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Contents of Vol. XLII.

No. 1.

THE OXYGEN ETHERS OF THE DIALKYLUREAS. By Ralph H. McKee. 1
CONTRIBUTIONS FROM THE SHEFFIELD LABORATORY OF YALE UNIVERSITY:

CLXVII.—*Researches on Pyrimidines: The Preparation of 3-Methyl- and 3-Benzyluracil.* By Henry L. Wheeler and Treat B. Johnson 30
CONDUCTIVITY AND VISCOSITY IN MIXED SOLVENTS CONTAINING GLYCEROL. By M. R. Schmidt and Harry C. Jones . . . 37

REVIEWS.

Die Lagerung der Atome im Raume 95
The Elements of Physical Chemistry 96
Qualitative Analyse vom Standpunkte der Ionenlehre 97
General Chemistry for Colleges 98
A Text-Book of Botany and Pharmacognosy 98
Principles and Practice of Agricultural Analysis 99

No. 2.

CONTRIBUTIONS FROM THE SHEFFIELD LABORATORY OF YALE UNIVERSITY:

CLXVIII.—*Researches on Pyrimidines: The Preparation of 1,4-Dimethyluracil and of the Monobenzyl Derivatives of 4-Methyluracil.* By Henry L. Wheeler and David F. McFarland 101
ON THE THEORY OF INDICATORS AND THE REACTIONS OF PHTHALEINS AND THEIR SALTS. By S. F. Acree and E. A. Slagle . . . 115
EXPERIMENTS ON THE RADIOACTIVITY OF ERBIUM, POTASSIUM AND RUBIDIUM COMPOUNDS. By W. W. Strong 147
PRODUCTION OF CARBON DIOXIDE FROM SOLUTIONS OF COMPOUNDS OF SILICON, ZIRCONIUM, BISMUTH, AND THORIUM. By Sir William Ramsay 150

REPORT.

Relation between Crystalline Form and Chemical Constitution . . 158

REVIEWS.

Exercises in Practical Physiological Chemistry 179
Untersuchung und Nachweis organischer Farbstoffe auf spektroskopischem Wege 180
Ion 181
Elektrolytische Zähler 182

No. 3.

CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF CORNELL UNIVERSITY:

- Tetrachlorgallein and Some of Its Derivatives.* By W. R. Orndorff and T. G. Delbridge 183

CONTRIBUTIONS FROM THE SHEFFIELD LABORATORY OF YALE UNIVERSITY:

- CLXIX.—*Researches on Pyrimidines. Sulphur Derivatives of 5-Hydroxyuracil: Preparation of 5-Benzylmercaptouracil and 5-Benzylmercaptocytosine.* By Treat B. Johnson and Herbert H. Guest 271

CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF HARVARD COLLEGE:

- A Modification of Scheibler's Extractor for Use with Large Quantities of a Solid.* By C. Loring Jackson and Latham Clarke 287

REVIEWS.

- Die neueren Fortschritte auf dem Gebiete der Radioaktivität (von Anfang 1906 bis Mitte 1908) 291
 Die englischen elektrochemischen Patente 291
 Grundriss der allgemeinen Chemie 291
 Die edlen und die radioaktiven Gase 292

No. 4.

FROM THE DIVISION OF CHEMISTRY, HYGIENIC LABORATORY, U. S. PUBLIC HEALTH AND MARINE HOSPITAL SERVICE, WASHINGTON, D. C.:

- On the Decomposition of the Leucosulphonic Acids of Rosaniline Hydrochloride and Crystal-Violet in Aqueous Solution.* By J. H. Kastle 293

CONTRIBUTION FROM KENT CHEMICAL LABORATORY OF THE UNIVERSITY OF CHICAGO:

- On the Action of Fehling's Solution on Malt Sugar.* By W. Lee Lewis 301

UREIDES AND CYANAMIDES OF THE OXYFATTY ACIDS. By Erik Clemmensen and Arnold H. C. Heitman 319

CONTRIBUTIONS FROM THE SHEFFIELD LABORATORY OF YALE UNIVERSITY:

- CLXX.—*Researches on Amines: Synthesis of Methylphenylethylamine.* By Treat B. Johnson and Herbert H. Guest 340

- CLXXI.—*Researches on Pyrimidines: Dimethyl Derivatives of 2-Aminopyrimidine. Preparation of 2-Methylamino-5-Methylpyrimidine.* By Treat B. Johnson and Kenneth G. Mackenzie 353

REVIEWS.

Jahrbuch der Chemie	370
Kurzes Lehrbuch der organischen Chemie	371
Neuere theoretische Anschauungen auf dem Gebiete der organischen Chemie	372
Anleitung für das organisch-präparative Practicum	373
Quantitative Experiments in General Chemistry	373
Gesättigte Salzlösungen von Standpunkt der Phasenlehre	374
Meat and Food Inspection	374
Errata	374

No. 5.

VINYLPHENYL KETONE AND SOME OF ITS HOMOLOGUES. By E. P. Kohler	375
CONTRIBUTION FROM THE KENT CHEMICAL LABORATORY OF THE UNIVERSITY OF CHICAGO:	
<i>On the Action of Fehling's Solution on Galactose.</i> By Ernest Anderson	401
CONTRIBUTIONS FROM THE SHEFFIELD LABORATORY OF YALE UNIVERSITY:	
CLXXII.— <i>Researches on Pyrimidines: The Action of Methyl Iodide and of Benzyl Chloride upon 2-Oxy-4-Methyl-6-Methylmercaptopyrimidine.</i> By Henry L. Wheeler and David F. McFarland	431
CLXXIII.— <i>Researches on Halogen Amino Acids: Iodine Derivatives of Paratoluidine; 3,5-Diod-4-aminobenzoic Acid.</i> By Henry L. Wheeler and Leonard M. Liddle	441
LEAD SILICATES: THERMAL ANALYSIS OF THE SYSTEM PbO-SiO_2 . By H. C. Cooper, L. I. Shaw and N. E. Loomis	461

OBITUARY.

Samuel William Johnson	474
----------------------------------	-----

REVIEWS.

Die chemische Industrie	475
A Course in Inorganic Chemistry for Colleges	475
An Intermediate Course of Laboratory Work in Chemistry	476
Tables of Properties of Over Fifteen Hundred Common Inorganic Substances	476

No. 6.

THE OXIDATION OF HYDROXY DERIVATIVES OF BENZALDEHYDE, ACETOPHENONE AND RELATED SUBSTANCES. By H. D. Dakin	477
---	-----

CONTRIBUTIONS FROM THE SHEFFIELD LABORATORY OF YALE UNIVERSITY:

CLXXIV.—*Researches on Halogenamino Acids: Iodine Derivatives of Orthotoluidine. The 3-Iodaminobenzoic Acids.*

By Henry L. Wheeler and Leonard M. Liddle . . . 498

CLXXV.—*Researches on Pyrimidines: Synthesis of 5-Cyanuracil.* By Treat B. Johnson . . . 505

CONTRIBUTIONS FROM THE CHEMICAL LABORATORY OF THE UNIVERSITY OF CINCINNATI:

The Preparation of Hydroxamic Acids from Hydroxylamine Salts of Organic Acids. By Lauder William Jones and

Ralph Oesper . . . 515

THE EFFECT OF TEMPERATURE AND DILUTION ON THE CONDUCTIVITY OF ORGANIC ACIDS IN AQUEOUS SOLUTION. By George F. White

and Harry C. Jones . . . 520

REPORT.

Recent Progress in Our Knowledge of the Radioactive Elements . 541

REVIEWS.

Das Arbeiten mit farbenempfindlichen Platten . . . 558

Jahrbuch der Elektrochemie und angewandten physikalischen Chemie 558

On the Calculation of Thermochemical Constants . . . 559

Les Densités des Solutions Sucrées à Différentes Températures . 559

Histoire du Développement de la Chimie depuis Lavoisier jusqu'à nos Jours . . . 559

Einführung in die allgemeine und anorganische Chemie auf elementarer Grundlage . . . 560

The Chemistry and Literature of Beryllium . . . 561

Laboratory Notes on Industrial Water Analysis . . . 562

Index . . . 563

AMERICAN CHEMICAL JOURNAL

THE OXYGEN ETHERS OF THE DIALKYLUREAS.

BY RALPH H. MCKEE.

This paper is a contribution to our knowledge of the asymmetrical methyl (and ethyl) dialkylisoureas, $R_2N.COCH_3 = NH$, where R is CH_3 , C_2H_5 , C_3H_7 , C_4H_9 , or C_5H_{11} . These compounds were prepared and studied partly for comparison with the mother substance, methyl isourea, and with isoureas containing aromatic residues linked to nitrogen and other related compounds; and partly to serve as material for the study of certain typical organic reactions by the methods of physical chemistry.¹

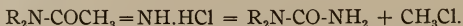
In general, it may be said that the methods of preparation and the reactions were much like those of the analogous aromatic substances which have been previously studied, except for differences due to the very much greater sensitiveness of the members of the present series to heat and reagents. In the preparation of the lowest member of the present series, methyl dimethylisourea, $(CH_3)_2N.COCH_3 = NH$, the methods had to be much modified owing to its great volatility with ether and alcohol vapors, its complete miscibility with all solvents, and the rapid deliquescence and decomposition of

¹ To be given in a later paper.

its salts even at room temperature. The exact methods developed for the preparation of this new class of ethers, by the action of sodium alcoholate on the dialkylcyanamide, will be described in the experimental part.

The basic oils obtained have densities which decrease as the alkyl radicals joined to nitrogen increase from methyl to isoamyl and are always less than that of water, the maximum density being about 0.97. The highest member, the isoamyl compound, is but slightly soluble in water, one part in 1500, but the solubility increases as we go down the series until, with methyl dimethylisourea, we find complete solubility in every ratio with all common solvents. The intermediate members show the unusual phenomenon of being several times as soluble in cold water as in warm water. The substances are strong enough bases to affect the skin in the same manner as a solution of potassium hydroxide, to dissolve aluminium hydroxide, and to give perfectly neutral salts with one equivalent of the strong acids. The only slightly soluble salt which has been found for any of these bases is the one formed with hydroferrocyanic acid. This acid also gives, with the isoureas containing aromatic residues linked to nitrogen, slightly soluble salts which, as well as those described in the present paper, are acid salts containing but one molecule of the base to one of the acid.

The hydrochlorides are readily precipitated by the addition of dry hydrogen chloride to the cold ether or ligroin solution of the base. On heating these hydrochlorides, methyl chloride and the urea are formed quantitatively according to the equation

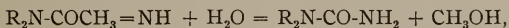


Even at room temperature, this reaction readily takes place, *e. g.*, methyl diisoamylisourea hydrochloride practically completely decomposed in three months in this manner. Methyl dimethylisourea hydrochloride is but slightly more stable.

On heating a water solution of a hydrochloride at 100°, the same decomposition into a dialkylurea and alkyl chloride was found to occur quickly. Hitherto, it has been considered

that alkyl chloride splits off the easier the more negative the groups attached to nitrogen, but the hydrochlorides of this series have the most basic alkyls possible joined to nitrogen and yet give alkyl chloride far more easily than the analogous aromatic bodies. One of the more interesting new developments is that this formation of alkyl chloride and urea, on heating the water solution of the hydrochloride, is found to be a decomposition of the unionized portion and is not a reaction in which the ions take part.

Heated with water, the higher members react but slowly, the lower members more rapidly (65 per cent in two hours at 100°), but in each case the reaction seems to proceed simply and completely according to the equation



with no evidence of the formation of ammonia and a urethane.

By heat alone, *i. e.*, without a solvent, the lower members are decomposed into the cyanamide and alcohol from which the isourea was originally prepared.

EXPERIMENTAL PART.

Methyl Diisobutylisourea (Methyl Diisobutylimidocarbamate), $(C_4H_9)_2N.C(:NH)OCH_3$.—The preparation of this isourea from diisobutylcyanamide¹ was attempted, but without success, according to the method by which Lengfeld and Stieglitz² brought about the addition of alcohol to carbodiimide, *i. e.*, by heating in sealed tubes. In no case was any alkaline oil formed by heating the cyanamide with absolute alcohol, though temperatures varying from 100° to 225° were tried.

A moderate degree of success attended the attempt to bring about the addition of alcohol by the method used by Pinner³ in the preparation of imidoethers from acid nitriles and by which I have prepared isoureas containing aromatic residues linked to nitrogen.⁴ Diisobutylcyanamide (1 mol.) was dis-

¹ McKee: *THIS JOURNAL*, **36**, 210 (1906).

² *Ber. d. chem. Ges.*, **27**, 926 (1894).

³ *Imidoäther und ihre Derivate* (1892), page 3.

⁴ Stieglitz and McKee: *Ber. d. chem. Ges.*, **32**, 1495 (1899); **33**, 808 (1900). McKee: *THIS JOURNAL*, **26**, 215 and ff. (1901).

solved in absolute alcohol (10 mol.) and dry hydrogen chloride (1 mol.) slowly run into the resulting solution, kept cold by ice. After standing a week at room temperature, dilution with water no longer brought about the separation of an oil, unchanged diisobutylcyanamide, and the action was considered to be complete. The excess of alcohol was removed by evaporation in a vacuum over sulphuric acid and solid caustic potash. Crystals of the hydrochloride separated in fair amount. These were washed with ether and, after recrystallization from ethyl acetate, analyzed by titration with standard silver nitrate. 0.3088 gram required 13.74 cc. 0.1 N silver nitrate (chromate indicator); calculated for $(C_4H_9)_2N.C(:NH).OCH_3.HCl$, 13.86 cc. By treatment of the hydrochloride with caustic potash, the free methyl diisobutylisourea was obtained. The method gives about sixty per cent of the possible yield, calculated from the cyanamide taken, but requires much time for the completion of the reaction and the isolation of the hydrochloride. The time taken by the reaction may be shortened to several hours by heating the mixture to 40° – 50° , but this hastening of the reaction is accompanied by some decomposition of the hydrochloride formed.¹

The method finally found to give the best results, with a minimum of expenditure of material and time, was that of adding the diisobutylcyanamide (1 mol.) to a solution of sodium (1.1 atoms) in dry methyl alcohol (10 mol.).² The resulting solution was either kept at room temperature a week or, more commonly, the completion of the reaction hastened by heating at 55° for two hours. To the mixture, cooled below 15° , dilute hydrochloric acid was added until the reaction was almost neutral, and any unchanged diisobutyl-

¹ When the hydrochloride of the isourea to be prepared is sufficiently stable towards heat, this shortening of the time can often be used with considerable advantage, *e. g.*, the time for the completion of the reaction by which methyl isourea (Stieglitz and McKee: *Ber. d. chem. Ges.*, **33**, 1517 (1900)) is formed from cyanamide may be shortened from several days to about half an hour, if a temperature of 40° is used. A decrease in the amount of alcohol from 25 to 2 molecules for each molecule of cyanamide used was found not to decrease the yield, but only to lengthen the time at 40° from 0.5 hour to 2.5 hours. Similarly, in the preparation of methyl phenylisourea, an hour's heating at 40° is equivalent to several days' standing at room temperature (McKee: *THIS JOURNAL*, **26**, 228 (1901)). Cf. Bruce: *J. Am. Chem. Soc.*, **26**, 423 (1904).

² Cf. McKee: *THIS JOURNAL*, **36**, 209 (1906).

cyanamide was removed by extraction with ether. The hydrochloric acid solution was then treated with an excess of a strong solution of potassium hydroxide, the oil which separated taken up with ether, the ether solution washed several times with small amounts of water, and dried with anhydrous sodium sulphate. After distilling off the ether, the oil was distilled in a vacuum. The yield of pure substance was equal to the weight of the cyanamide taken.

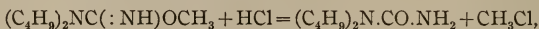
An attempt to replace the sodium methylate solution by an alcoholic solution of potassium hydroxide was only partially successful, the yield of the isourea being but forty per cent of the calculated.

Methyl diisobutylisourea is a colorless oily liquid having a basic, somewhat fishy odor. It boils at 102° (14 mm.), 116° (22 mm.), 135° (42 mm.), and with some decomposition at 218° – 222° (742 mm.). I was not able to effect the crystallization of the oil. Titration of the oil with standard acid showed it to be a strong monacid base. With methyl orange, 0.4928 gram required 26.44 cc. 0.1 N hydrochloric acid; calculated for $C_{10}H_{22}N_2O$, 26.45 cc. Density at 18.5° , referred to water at 4° (Westphal), 0.8933. It is readily soluble in all the ordinary organic solvents and slightly so in water, the resulting solution being strongly alkaline. Its solubility is greater in cold than in warm water. An approximate determination of its solubility by titration, with 0.1 N acid, of the saturated solution gave the following results: 1.14 parts at 0° , 0.94 parts at 10° , 0.61 parts at 21° , 0.49 parts at 30° , and 0.32 parts at 85° in 100 parts of water.

The imidoethers have been shown qualitatively to give, when heated in a current of dry hydrogen chloride, alkyl chloride and the acid amide. The similarity of the oils under discussion was shown in an experiment where dry hydrogen chloride was passed over 0.38 gram methyl diisobutylisourea in a test tube connected with an azotometer filled with 20 per cent sodium hydroxide solution.

At 0° , there was little action except that of absorption of the hydrogen chloride. On heating, there began at 45° a slow evolution of gas, which did not perceptibly increase

until 95° was reached, two-thirds of the gas evolved being obtained between 95° and 100° . In all there was obtained 43 cc. of a gas which was not absorbed by caustic soda and which burned with a green-tinged flame, showing it to be methyl chloride. The difference of 3 cc. between the volume of methyl chloride obtained, 43 cc., and the volume calculated, 46 cc., according to the equation



is probably due to the solubility of methyl chloride in the sodium hydroxide solution used in the azotometer.

In addition to proving the quantitative formation of methyl chloride, the presence of diisobutylurea, or rather its hydrochloride, in the residue was demonstrated and thus the reaction expressed by the above equation was shown to be the exclusive one. A solution of the residue in a little cold water gave, with an aqueous solution of oxalic acid, a precipitate, which, after drying on a porous plate, melted at 114° – 115° with evolution of gas. The melting point was unchanged when mixed with diisobutylurea oxalate¹ synthesized for comparison. The picrate was prepared by dissolving some of the residue in a little water, making the resulting solution slightly alkaline with ammonium hydroxide to remove the hydrochloric acid present, and adding a solution of picric acid in dilute alcohol. After drying on a porous plate, the salt melted at 90° , and when mixed with the synthetic urea picrate (see below), melting at 90° – 91° , the melting point was unchanged.

Methyl Diisobutylisourea Hydrochloride, $(\text{C}_4\text{H}_9)_2\text{N}.\text{C}(:\text{NH})\text{OCH}_3.\text{HCl}$.—Dry hydrogen chloride was passed into a solution of the isourea in cold absolute ether, the precipitated hydrochloride filtered off, and, after washing with ether, dried *in vacuo* over caustic potash and sulphuric acid.

Methyl diisobutylisourea hydrochloride is insoluble in ether and ligroin, slightly soluble in cold, but readily soluble in boiling benzene and ethyl acetate, and very soluble in

¹ Page 8.

water and alcohol. It may be recrystallized from hot ethyl acetate. When heated, it gives methyl chloride and the urea.

Methyl Diisobutylisourea Ferrocyanide, $(C_4H_9)_2N.C(:NH)OCH_3.H_4Fe(CN)_6$.—In an attempt to obtain an easy scheme of identification for the isoureas, the salts of a large number of acids were made. All of these were found to be extremely soluble, and consequently difficult to purify, except the acid ferrocyanides. These ferrocyanides did not, however, give the definite and characteristic melting points desired.

On adding a solution of ferrocyanic acid¹ to methyl diisobutylisourea, no precipitation took place until enough had been added to make the solution distinctly acid. There then appeared a very fine white precipitate of the acid salt² containing one molecule of the base to one of the acid. This salt is so insoluble that the filtrate does not become blue on treatment with ferric chloride. It seems to be stable at room temperature, but when heated to 100° in an air bath, there is decomposition with the formation of an ill-smelling vapor (isonitrile?) and a darkening in color of the salt.

An analysis for iron, by moistening with sulphuric acid and igniting, gave 13.54 and 13.55 per cent iron; calculated for $C_{16}H_{26}ON_8Fe$, 13.89 per cent.

Diisobutylurea, $(C_4H_9)_2N.CO.NH_2$, is not described in the literature and so was prepared in order that its properties might be known and the identity of the product formed by methyl diisobutylisourea, when heated with hydrogen chloride or with hydrochloric acid, be made certain.

Diisobutylamine was neutralized with dilute hydrochloric acid and caused to react with an equivalent amount of potassium isocyanate by heating on a water bath. The viscous oil which separated was taken up with ether. The resulting ethereal solution was washed with water, dried with fused

¹ Baeyer and Villiger: Ber. d. chem. Ges., **34**, 2687 (1901).

² Similar slightly soluble ferrocyanides are formed by ethyl diphenylisourea, methyl phenylmethylisourea, ethyl phenylisourea, methyl dipropylisourea and methyl *p*-tolylisourea. The corresponding salts of methyl phenylisourea and ethyl isourea are readily soluble and that of methyl dimethylisourea is only moderately soluble. Ferrocyanic acid gives similar salts but they are all somewhat more soluble. The salts of both acids are much more soluble in alcohol than in water.

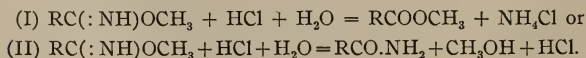
calcium chloride, and the ether removed by distillation. The oil distilled at about 180° (25 mm.) without decomposition. It is more soluble in cold than in warm water, the resulting solutions reacting neutral to litmus. It is readily soluble in all the ordinary organic solvents. Crystallization was started by rubbing some of the oil with a few drops of water. Inoculation of the remainder of the oil gave crystals which, after drying on a porous plate, melted at 72° – 74° .

Attempts to prepare a crystalline nitrate were without success. However, it was found to form slightly soluble crystalline salts with picric acid and oxalic acid.

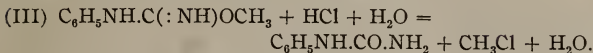
Diisobutylurea Oxalate, $[(C_4H_9)_2N.CO.NH_2]_2.H_2C_2O_4$, was precipitated as flat four-sided prisms on mixing aqueous solutions of the urea and oxalic acid. It melts at 115° with evolution of a gas. Analysis was made by titration with standard alkali and phenolphthalein. 0.1959 gram required 8.98 cc. 0.1 N potassium hydroxide; calculated for $C_{20}H_{42}O_6N_4$, 9.02 cc.

Diisobutylurea Picrate, $(C_4H_9)_2N.CO.NH_2.C_6H_2(NO_2)_3OH$, was prepared by the addition of a solution of picric acid in dilute alcohol to an aqueous solution of the urea. It separated as an oil which, on being cooled and rubbed with a glass rod, became crystalline. It was filtered off, washed with a little water, and dried on a porous plate. Microscopic needles melting at 90° – 90.5° . Dissolved in warm water, cooled, and inoculated with some of the crystals previously obtained, it melted at 90° – 91° . It melts without decomposition, for, after allowing it to solidify in the melting point tube, a second heating gave the same melting point. Its composition was made certain by titration with 0.1 N potassium hydroxide and phenolphthalein. 0.4684 gram required 12.15 cc.; calculated for $C_{15}H_{23}O_8N_5$, 11.67 cc.

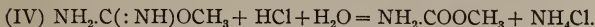
Action of Dilute Hydrochloric Acid on Methyl Diisobutylisourea.—In the presence of dilute acid, the imidoethers are readily hydrolyzed according to the equations



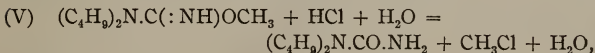
Phenylisourea ethers¹ have been shown to decompose, without hydrolysis according to the equation



With the unsubstituted isourea, $NH_2.C(:NH)OCH_3$, while the main reaction is according to (III), with formation of urea and methyl chloride, there is formed at the same time a little urethane² according to an equation analogous to (I):

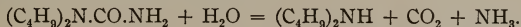


In the study of the action of dilute acid on dialkylisoureas of the type of methyl diisobutylisourea, it was early shown that the principal action, at 100° , was analogous to that with the phenylisourea ethers, *viz.*, a decomposition into alkyl chloride and the urea according to the equation



water having taken no part in the reaction.

The attempt to determine if this was the only kind of decomposition undergone was made difficult by the fact that, under the conditions of the experiment, the urea first formed is rapidly hydrolyzed with formation of diisobutylamine, ammonia, and carbon dioxide:



The diisobutylamine set free by the hydrolysis of the urea is a strong base and takes a part of the hydrochloric acid unto itself, thereby reducing the amount of the isourea present as the hydrochloride. When the reactions of the amyl member are described, it will be shown that the formation of methyl chloride is due to the decomposition of the unionized isourea hydrochloride.

One and twenty-two hundredths grams of methyl diisobutylisourea hydrochloride³ were dissolved in 2.5 cc. water and the resulting solution, approximately 1.5 N, was heated

¹ McKee: *THIS JOURNAL*, **26**, 219 (1901).

² *Ibid.*, **26**, 250 (1901).

³ Page 6.

in a test tube in a boiling water bath. The gas evolved was collected in an azotometer filled with 20 per cent sodium hydroxide. In four hours, gas had ceased to be evolved and the contents of the test tube had become strongly alkaline, due to the diisobutylamine formed by hydrolysis of diisobutylurea. A little hydrochloric acid was added to the contents of the tube and the whole heated for an hour longer. This caused the evolution of 28 cc. more methyl chloride, and made a total of 124 cc. (20° and 745 mm.), equivalent to 111 cc. (0° and 760 mm.). For 1.22 grams of the hydrochloride, if the decomposition into the urea and alkyl chloride is quantitative, the calculated amount of methyl chloride is 121 cc. (0° and 760 mm.). The solubility of methyl chloride in the aqueous sodium hydroxide accounts, at least in large part, for the 10 cc. discrepancy between the volume found and that calculated for a quantitative decomposition into the urea and alkyl chloride.

The gas was identified as methyl chloride by its burning with a green-edged flame. The oil which had separated in the tube was identified as the urea by the abundant precipitate melting at 115° which it gave with oxalic acid. This melting point was not changed when the substance was mixed with the synthetic diisobutylurea oxalate¹ melting at 115° . It likewise gave a picrate melting at 90° – 91° , which, when mixed with the synthetic diisobutylurea picrate, still melted at 90° – 91° .

That there was no urethane formation was shown by the lack of the odor characteristic of the urethanes, $(C_4H_9)_2N.CO_2Alk$, and by the fact that a definite and sharp end point was obtained when the hydrochloride solution, after being heated, was made neutral to methyl orange by 0.1 N acid. It will be shown below that the substituted urethanes have a characteristic odor and are so distinctly basic that, in their presence, a base cannot be titrated to a sharp neutrality point.

Methyl Diisobutylcarbamate (*Diisobutylmethylurethane*), $(C_4H_9)_2N.CO_2CH_3$, was synthesized in order to obtain accurate knowledge of its properties and obviate any likelihood of

¹ Page 8.

overlooking its presence, in even small amounts, if it had been formed by the action of dilute acid or of water on the isourea. It was prepared by adding an ethereal solution of diisobutylamine (1 mol.) to a slight excess (1.2 mol.) of twenty per cent potassium hydroxide and then, with vigorous shaking after each addition, slowly adding to the resulting mixture, kept below 10°, an ethereal solution of methyl chlorcarbonate. The ethereal and aqueous layers were separated, and the former, after being washed with dilute acid and water, was dried with fused calcium chloride.

The oil remaining after distilling off the ether boils at 204° (753 mm.). The yield is excellent. It is readily soluble in the ordinary organic solvents and slightly in water. It is readily soluble in concentrated sulphuric acid and from this solution is precipitated unchanged on the addition of water. It has a persistent and characteristic odor similar to that given by the analogous dipropyl- and dimethylurethanes.

That it is slightly basic was shown by treating three drops of the oil with 30 cc. water, a drop of methyl orange solution, and adding 0.1 N acid from a burette. About 0.20 cc. more acid was required to pass through the neutral tints, *i. e.*, from the point where the pink *began* to appear until a clear pink, free from yellow, was obtained, than in a parallel experiment with distilled water.

This somewhat basic character of the urethane was shown even more plainly by a comparison of its solubility in water and acids. The determinations were made by filling a previously calibrated Babcock milk bottle with the solvent and then adding about half a cubic centimeter of the oil. The volume of the oil was read exactly by the divisions on the neck, and the bottle corked and shaken well for thirty minutes. Rotation in the centrifugal machine now caused the undissolved oil to collect in the neck. The volume was again read and the decrease gave the volume of the oil dissolved in the amount of solvent taken. No account was taken of the possible increase in volume of the oil due to the solution of water in the oil. Its effect would be very slight and in any case affect the several determinations almost equally. At 18°,

this urethane, methyl diisobutylcarbamate, was found to require approximately 4000 parts water, 1200 parts dilute (3 N) hydrochloric acid, and 200 parts concentrated (12 N) hydrochloric acid for solution.

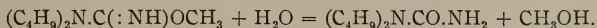
That the basic character found is not peculiar to this substance nor due to an impurity, but is common to this class of oils, was shown by a careful examination of the effect of several other urethanes on the neutrality of methyl orange and by comparisons of their solubilities in water and in dilute and concentrated acids.

Ethyl Diisobutylcarbamate (Diisobutylurethane), $(C_4H_9)_2N.COOC_2H_5$.—The ethyl ester was prepared from ethyl chlorcarbonate, by the method just described for methyl diisobutylcarbamate, with a yield of 90 per cent of the calculated amount. It boils at 100° (13 mm.) and 203° (757 mm.). In its odor, solubilities, and slightly basic character, as shown by titration with standard acid and methyl orange, it is very similar to the methyl ester. Determination of its solubility at 17° by the centrifugal method gave the following results: one part of ethyl diisobutylcarbamate dissolves in 320 parts, by volume, concentrated (12 N) hydrochloric acid, 640 parts dilute (3 N) hydrochloric acid, and 1600 parts of water.

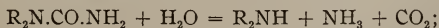
That the greater solubility in acid is not due to hydrolysis of the oil by the acid was shown when a bottle containing the strong acid and the urethane was well shaken, kept overnight lying on its side, in order to insure thorough contact of the oil with the acid, and the next day the volume of the urethane, remaining undissolved, redetermined. The volume of the oil had not decreased by an amount greater than the error of reading, 0.006 cc.

Action of Water on Methyl Diisobutylisourea.—One and twenty-five hundredths grams of methyl diisobutylisourea, with ten times that weight of water, were heated at 100° in a sealed tube for 11 hours. The tube opened with no pressure. The contents of the tube were carefully transferred to a separatory funnel and titrated with normal hydrochloric acid and methyl orange. 4.42 cc. were required; calculated for 1.25 grams isourea if no decomposition had taken place,

6.67 cc. The end point was perfectly sharp, indicating the absence of slightly basic substances like diisobutylurethane or diisobutylcyanamide. The absence of these possible reaction products was made certain by the fact that the methyl orange solution did not change color, *i. e.*, become more acid, when the solution was shaken with ether. Diisobutylurethane, $(C_4H_9)_2NCOOCH_3$, and diisobutylcyanamide, $(C_4H_9)_2NCN$ are weak bases slightly soluble in water and very soluble in ether and as such would be largely extracted by the ether from the water solution and leave the latter more acid. No change of the neutrality point could be detected. The water solution was extracted three times with ether and the ether extract washed with water, dried with granular calcium chloride, and evaporated, leaving a residue of yellowish oil. This oil was dissolved in two cubic centimeters of alcohol and a saturated aqueous solution of oxalic acid added in excess. The crystals which separated weighed 0.48 gram and melted at 110° . Recrystallized, they melted at 115° alone, and when mixed with the synthetic diisobutylurea oxalate¹. Forty-eight hundredths gram of the urea oxalate is equivalent to a decomposition of 0.41 gram of the isourea according to the equation



The titration with acid would indicate that 0.42 gram of the isourea had reacted according to the above equation. The agreement of these two determinations is partially due to two errors of measurement being in opposite directions and apparently of about equal amounts. The first is that the weight of the oxalate obtained is undoubtedly low to the extent of its solubility in the dilute alcohol solution from which it was precipitated. The second error is due to the fact that there is some hydrolysis of the diisobutylurea:



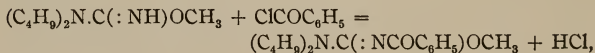
which, increasing the alkalinity of the solution, reacts in the titration to decrease the apparent amount of isourea decom-

¹ Page 8.

posed. Each of these errors is very small and there seems to be no reason for doubting that the isourea reacts with water to form only diisobutylurea and methyl alcohol. It is thus seen that the action of water is simple and entirely analogous to the action previously shown qualitatively with the isoureas¹ and imidoethers.²

Action of Benzoyl Chloride on Methyl Diisobutylisourea.—It has been shown³ that the monophenylated oxygen ethers of urea, $C_6H_5NH.C(:NH)OCH_3$, can be benzoylated quite readily without the loss of the alkyl group attached to oxygen, the reaction proceeding along the same lines as with the imidoethers which contain a replaceable hydrogen atom attached to nitrogen. Dains,⁴ with the symmetrical diphenylated isoureas, $C_6H_5NH.C(:NC_6H_5)OAlk$, found that acyl chlorides reacted with the formation of alkyl chloride and a trisubstituted urea, a reaction quite different from that mentioned above, but entirely analogous to that found by Wheeler and Walden⁵ to occur when imidoethers having no hydrogen directly bound to the nitrogen are acted upon by acyl chlorides.

With the isoureas described in the present paper, the action with acyl chlorides was found to be exclusively a replacement of the imide hydrogen by the acyl group according to the equation



with no evidence of urea and methyl chloride formation. In other words, the reaction is entirely analogous to that obtained with the monophenylated isoureas and the ordinary imidoethers and shows no similarity to that of Dains's diphenylisoureas, or Wheeler and Walden's imidoethers of the type $RN:CH.OC_2H_5$.

Methyl diisobutylisourea was treated, in the presence of an excess of ten per cent caustic potash solution, with an

¹ McKee: *THIS JOURNAL*, **26**, 218 (1901).

² Wheeler: *Ibid.*, **17**, 398 (1897).

³ McKee: *THIS JOURNAL*, **26**, 226 (1901).

⁴ J. Am. Chem. Soc., **21**, 181 (1899).

⁵ *THIS JOURNAL*, **19**, 130 (1898).

equivalent amount of freshly distilled benzoyl chloride dissolved in absolute ether. At 5° , the reaction was complete in ten minutes. The ethereal layer was removed, washed with one per cent acid to remove any unchanged methyl diisobutylisourea, and with water, and then dried with anhydrous sodium sulphate. Evaporation of the ether *in vacuo*, over concentrated sulphuric acid, left the methyl benzoyldiisobutylisourea as a viscid colorless oil, corresponding in amount to 92 per cent of the calculated. It is readily soluble in ether, chloroform, and alcohol, and slightly in ligroin, insoluble in water and in strong sodium hydroxide solution.

When 0.41 gram of the oil was gradually heated to 100° in a tube, in a current of dry hydrogen chloride, there was some evolution of gas even at 20° , but the evolution of gas did not become vigorous until the temperature approached 50° . The volume of methyl chloride obtained in the azotometer, which had been filled with 20 per cent sodium hydroxide, was only 3 cc. less than the calculated, an amount which was probably entirely due to the solubility of methyl chloride in the aqueous sodium hydroxide used. The residue in the tube was found to contain benzoyl chloride, identified by its odor and that of the ester formed by heating it with alcohol, thus indicating that the benzoyldiisobutylurea first formed had, under the action of the excess of hydrogen chloride, decomposed to some extent. No attempt was made to identify the other products formed. That benzoyl chloride actually is formed on heating benzoyldiisobutylurea¹ under these conditions was shown in a supplementary experiment where the urea alone was subjected to the action of hydrogen chloride and heat.

Action of Dilute Hydrochloric Acid on Methyl Benzoyldiisobutylisourea.—Though containing the strongly negative benzoyl group, methyl benzoyldiisobutylisourea, when heated at 100° with dilute acid, was found to react in a manner perfectly analogous to that observed with the other isoureas, *i. e.*, quantitative decomposition into methyl chloride and urea took place on heating the oil with an equivalent of normal

¹ Page 16.

hydrochloric acid. The experiment was carried out by attaching the test tube, containing the isourea and acid, by means of a capillary tube to a Lunge nitrometer and measuring the amount of methyl chloride evolved when the test tube was heated in a boiling water bath. The urea, after one crystallization from 50 per cent alcohol, melted at 121° – 122° ; mixed with pure benzoyldiisobutylurea (see below), it melted $0^{\circ}.5$ higher.

Methyl Benzoyldiisobutylisourea Hydrochloride, $(C_4H_9)_2N.C(:NCOC_6H_5)OCH_3.HCl$, was precipitated when a solution of the isourea, in low boiling ligroin, was cooled to -15° by a freezing mixture, and treated with dry hydrogen chloride. It first separated as an oily film which, in a few minutes, became crystalline. The solid was filtered off, washed with cold (-10°) ligroin, and then transferred to a porous plate. In a minute it had become pasty and in another minute it had changed to a viscous oil and was rapidly giving off bubbles of a gas. This gas burned with a green-edged flame and was probably methyl chloride. The material remaining on the porous plate was a solid which, after crystallization from 50 per cent alcohol, was identified by its melting point and solubilities as benzoyldiisobutylurea (see below). It is thus evident that a hydrochloride is formed but that at room temperature it rapidly decomposes into alkyl chloride and the urea.

Benzoyldiisobutylurea, $(C_4H_9)_2N.CO.NHCOC_6H_5$.—An attempt was first made to synthesize this urea by benzoylating diisobutylurea, in pyridine solution, but without success. The urea was prepared by dissolving the corresponding isourea in absolute ether, adding an excess of dry hydrogen chloride, and then allowing the ether to evaporate at room temperature, the hydrochloride first formed decomposing with formation of the urea. After three crystallizations from 50 per cent alcohol, the urea melted at 123° – $123^{\circ}.5$ without decomposition. It is insoluble in cold water, slightly in hot water, but readily in ether and alcohol and caustic alkali solution. From the latter it is precipitated unchanged by the addition of acid. From 50 per cent alcohol it crystallizes as thick rhombic

plates. Analysis: 0.1539 gram gave 0.3931 gram CO_2 and 0.1200 gram H_2O .

	Calculated for $\text{C}_{16}\text{H}_{24}\text{O}_2\text{N}_2$.	Found.
C	69.50	69.66
H	8.77	8.74

Methyl Diisoamylisourea (*Methyl Diisoamylimidocarbamate*), $(\text{C}_5\text{H}_{11})_2\text{N.C}(\text{:NH})\text{OCH}_3$, was prepared from diisoamylcyanamide¹ and sodium methylate, by the same method as was used in the preparation of the diisobutylisourea. The yield is excellent. Methyl diisoamylisourea boils at 125° (7 mm.), 133° (12 mm.), and 153° (30 mm.). It is readily soluble in the common organic solvents, but is only soluble in 1500 parts water at 15° . Its density is 0.8860 at 18° , referred to water at 15° (Westphal). Titrated with 0.1 N hydrochloric acid and methyl orange 0.4413 gram required 20.39 cc.; calculated for $\text{C}_{12}\text{H}_{26}\text{ON}_2$, 20.59 cc.

Methyl Diisoamylisourea Hydrochloride, $(\text{C}_5\text{H}_{11})_2\text{N.C}(\text{:NH})\text{OCH}_3.\text{HCl}$.—This salt was prepared by precipitation at 10° from the ligroin solution of the isourea with hydrogen chloride. The salt was dried in a vacuum over solid potassium hydroxide and paraffin. It was found to melt, with evolution of a gas, at 104° . An analysis was made by titration with standard silver nitrate solution, using chromate indicator: 0.3516 gram required 14.03 cc.; calculated, 14.02 cc.

The salt decomposes spontaneously on being kept at room temperature; in six weeks it was more than one-third decomposed and in three months the decomposition was almost complete. The product left was an oil which was identified as diisoamylurea by its oxalate melting at 102° alone, and also when mixed with the synthetic diisoamylurea oxalate (see below).

Diisoamylurea, $(\text{C}_5\text{H}_{11})_2\text{N.CO.NH}_2$.—This urea was prepared by warming a solution of the amine sulphate with an equivalent amount of potassium isocyanate. The oil which separated was taken up with ether, and the ethereal solution washed

¹ McKee: THIS JOURNAL, 36, 210 (1906).

with very dilute acid and water and dried. Evaporation of the ether left an oil which could not be made to crystallize.

The urea did not give a slightly soluble nitrate. Its picrate was slightly soluble but did not crystallize. Oxalic acid added to a solution of the urea in very dilute alcohol at once gave a crystalline precipitate. The crystals of the oxalate are four-sided prisms having dome ends and melting at $102^{\circ}.5$ with evolution of a gas. 0.6662 gram required 27.04 cc. 0.1 N sodium hydroxide, with phenolphthalein as indicator; calculated for $[(C_5H_{11})_2N.CO.NH_2]_2H_2C_2O_4$, 27.15 cc.

Action of Dilute Hydrochloric Acid on Methyl Diisoamylisourea.—Methyl diisoamylisourea heated with an equivalent of normal hydrochloric acid gave methyl chloride in quantity and an oil lighter than water. The oil was identified as diisoamylurea by its oxalate melting at $102^{\circ}.5$ alone and when mixed with the synthetic urea oxalate. The contents of the tube gave a sharp end point to methyl orange and 0.1 N acid, thus indicating that no urethane or diisoamylcyanamide had been formed.

Measurements of the rate of evolution of methyl chloride from solutions of various concentrations and in the presence of a substance having a common ion indicate that the reaction is one of the first order and due to the decomposition of the unionized hydrochloride and is not a reaction in which the ions take a part. Exact measurements of the percentage of ionization of the salt and rate of the decomposition into methyl chloride and diisoamylurea are under way and the results will be published shortly.

Ethyl Diisoamylisourea (*Ethyl Diisoamylimidocarbamate*), $(C_5H_{11})_2N.C(:NH)OC_2H_5$, was prepared in the same way as methyl diisobutylisourea. It boils at 158° (28 mm.). A water solution of the isourea blackens mercurous chloride and gives a white precipitate with a solution of mercuric chloride. The character of these mercury compounds has not yet been investigated.

Certain work by Bruce¹ was thought to favor the view that the silver salt of methyl phenylisourea has the formula

¹ J. Am. Chem. Soc., **26**, 435 (1904).

$C_6H_5NH.C(:NAg)OCH_3$ rather than the formula $C_6H_5NAg.C(:NH)OCH_3$ which would be expected from Bamberger's work¹ in which he showed that in the salts of phenylamidines the silver probably goes to the amide group. If, in the metallic salts of the isoureas, the metal is in the amide group then there is no reason why an isourea like $(C_5H_{11})_2N.C(:NH)OC_2H_5$, which has a replaceable imide hydrogen, should not give metallic salts, but if, on the other hand, these salts can only have the metal in the amide group, then such an isourea as the one just mentioned could not give a metallic salt. Attention may be called to the fact that all the isoureas which have been described in the literature² as giving metallic salts have a free hydrogen atom in the amide group.

Numerous attempts to prepare sodium, potassium, and silver salts of ethyl diisoamylisourea, by various modifications of the methods which have been previously used, were all without success. In no case was there any heat evolution or absorption, separation of a solid containing nitrogen, or any other evidence of salt formation, thus furnishing additional evidence in favor of the Bamberger view of the composition of such metallic salts.

Ethyl Diisoamylisourea Hydrochloride,

$(C_5H_{11})_2N.C(:NH)OC_2H_5.HCl$.—Ethyl diisoamylisourea was dissolved in absolute ether and dry hydrogen chloride passed into the solution kept below 10° . At first there was no separation of a solid, but after a minute or two, a fine mush of microscopic needles separated. The crystals were washed on the pump with absolute ether and dried *in vacuo* over caustic potash and sulphuric acid.

The salt is extremely soluble in water, the resulting solution being neutral to sensitive litmus. It melts at 125° with evolution of ethyl chloride. From the slowness with which the precipitation from the ether solution occurred when the salt was being prepared one would expect it to be distinctly soluble in ether. A determination of its solubility showed

¹ Ann. Chem. (Liebig), **273**, 277 (1893).

² McKee: THIS JOURNAL, **26**, 232 (1901). Bruce: J. Am. Chem. Soc., **26**, 434 (1904).

that 3.59 parts dissolve in 100 parts absolute ether at 17° . It is insoluble in ligroin. A chlorine determination was made by titration with 0.1 N silver nitrate and chromate indicator. 0.3712 gram required 14.02 cc.; calculated for $C_{13}H_{29}ON_2Cl$, 14.02 cc.

Methyl Dipropylisourea (*Methyl Dipropylimidocarbamate*), $(C_3H_7)_2N.C(NH)OCH_3$, was prepared by the general method¹ used with the other isoureas of this series.

Attempts to prepare sodium and silver salts were all unsuccessful, as were the similar experiments with ethyl diisourea which have just been described. Solutions of mercurous and mercuric salts gave with water solutions of this isourea black and white precipitates of the same appearance as those given by ammonia. The character of these complex salts has not been investigated.

Some of the isourea heated in a current of hydrogen chloride gave an almost quantitative yield of methyl chloride. A little of the alkyl chloride was set free below 20° but gas evolution did not become decided until about 100° ; the tube was not heated above 104° . A water solution of the residue left in the tube gave with oxalic acid an oxalate melting at 102° – 103° which, when mixed with the synthetic dipropylurea oxalate,² melted at the same temperature. With picric acid a picrate melting at 136° was obtained. As this is one degree higher than the melting point of the asymmetrical dipropylurea picrate as given by Zande³ the picrate was synthesized by his method and found to melt at 136° . Its identity was made certain by a titration with standard alkali and phenolphthalein; exactly the calculated amount was required to neutralize it.

Methyl Dipropylisourea Hydrochloride, $(C_3H_7)_2N.C(:NH)OCH_3.HCl$, was prepared by precipitation of the ether solution of the base with dry hydrogen chloride. Unlike the corresponding diethyl- and dimethylisourea hydrochlorides, to be described later, it is not appreciably deliquescent. That it decomposes readily at room temperature was

¹ Page 4; *THIS JOURNAL*, **36**, 209 (1906).

² Chancel: *Bull. Soc. Chim.* [**3**], **9**, 103 (1893).

³ *Rec. Trav. Chim.*, **8**, 224 (1889).

shown by a titration with silver nitrate and chromate indicator, three days after preparation, giving 17.97 per cent chlorine, and a second titration, a month later, 16.59 per cent; calculated for $C_8H_{19}ON_2Cl$, 18.21 per cent.

Action of Hydrochloric Acid on Methyl Dipropylisourea.—Methyl dipropylisourea hydrochloride, dissolved in double its weight of water, was heated at 100° for 1.5 hours. The sealed tube opened with considerable pressure due to methyl chloride. The contents of the tube, after heating, were neutral to methyl orange, thus showing the absence of any urethane formation by water taking part in the reaction.¹ The dialkylurethanes, $(C_3H_7)_2NCOOCH_3$ and $(C_3H_7)_2NCOOC_2H_5$, are weak bases giving indefinite end points with methyl orange and other indicators (see just below). The contents of the tube, when treated with oxalic acid, gave an abundant precipitate of the needle crystals of dipropylurea oxalate melting at 103° .

A second experiment, where the conditions were the same except that the temperature was 55° for 4.2 hours, showed a distinct but only very slight decomposition into dipropylurea and methyl chloride.

In a third experiment where the tube was kept at room temperature for two years the change into dipropylurea and methyl chloride had proceeded only to about the same extent as in the experiment where the tube was heated at 55° for 4.2 hours. The small amount of decomposition of the aqueous solution of the hydrochloride at 20° is somewhat surprising in view of the rate of decomposition of the dry salt at the same temperature shown just above.

Methyl Dipropylcarbamate (Dipropylmethylurethane), $(C_3H_7)_2N.COOCCH_3$, was prepared in the same manner as methyl diisobutylcarbamate.² Yield, 82 per cent. It boils at 191° (751 mm.). In its odor and indefinite neutrality point when treated with methyl orange and 0.1 N acid it closely resembles the urethanes previously described. It is much more soluble in cold water than in warm water. Approximate determinations of its solubilities at 18° by the centrifugal

¹ Page 9, Equation (IV).

² Page 10.

method¹ showed that one part, by volume, dissolves in 300 parts water, and in 160 parts of dilute (3 N) hydrochloric acid. It is readily soluble in all the ordinary organic solvents and in the concentrated acids, and from the last it is precipitated unchanged by the addition of water.

Ethyl Dipropylcarbamate (Dipropylurethane), $(C_3H_7)_2N.COOC_2H_5$.—The method of preparation, solubilities, and other properties of the ethyl ester are very similar to those of the methyl ester which has just been described. It boils about 200° (749 mm.).

Ethyl Dipropylisourea (Ethyl Dipropylimidocarbamate), $(C_3H_7)_2N.C(:NH)OC_2H_5$, was prepared by the same method as the methyl ester except that sodium ethylate was used instead of sodium methylate. It boils at 92° (10 mm.). As might be expected the reactions and properties are entirely similar to those which have been described for the methyl ester.

Stability of Ethyl Dipropylisourea.—It will be shown later that methyl dimethylisourea and ethyl isourea, when heated at 100° , are decomposed into the cyanamide and alcohol originally used in the preparation.

Heated for 50 hours at 100° ethyl dipropylisourea does not appreciably decompose. This was shown by the facts that there was no change in the boiling point; that the distillate from a solution of the oil in dilute hydrochloric acid failed to give the iodoform test for alcohol; that a titration with 0.1 N acid required for neutrality the amount of acid which would be required for the pure ethyl dipropylisourea; and that the end point to methyl orange in the above titration was sharp, thus showing the absence of even traces of dipropylcyanamide.

Methyl Dimethylisourea (Methyl Dimethylimidocarbamate), $(CH_3)_2N.C(:NH)OCH_3$.—The first attempts to prepare this isourea from dimethylcyanamide by the use of sodium methylate, according to the method used so successfully with the higher members of the series, gave evidence that the isourea had been formed but it was found impossible to separate it from the solvent by fractional distillation even when the

¹ Page 11.

fractionation was carried out at reduced pressure. Addition of gaseous hydrochloric acid and evaporation in a vacuum of the alcoholic solution was very tedious nor did it give the pure salt desired. Passing over the numerous attempts which met with only partial success we will describe the method which finally gave the pure substance. In general it may be said that the difficulties arose from the isourea being soluble in every ratio in water and all organic solvents and that its salts, in so far as tried, were deliquescent and extremely soluble in water and alcohol and decomposed on standing at room temperature.

Five and six-hundredths grams sodium (1.1 atoms) were dissolved in absolute methyl alcohol and the excess of alcohol boiled off until only about 25 grams (4 mol.) of the alcohol remained. To the cold mush of crystals of sodium methylate 14 grams (1 mol.) of dimethylcyanamide¹ were added. A clear yellowish solution resulted which, in about half a minute, became hot (80°), and needles of sodium methylate, NaOCH_3 , CH_3OH separated. The flask was cooled under the faucet to moderate the reaction. After standing 20 minutes there was added 100 cc. ether, a little methyl orange, and then, very carefully, and with thorough cooling with ice, concentrated hydrochloric acid drop by drop until the indicator gave a permanently acid reaction. Strong potassium hydroxide (1:2) was then added to the extent of 0.5 cc. more than needed to make the solution neutral. On removal and evaporation of the ethereal layer some unchanged dimethylcyanamide was recovered. The aqueous layer was extracted twice more with

¹ A still better method of preparation of this material than that previously described by the author in *THIS JOURNAL*, **36**, 211 (1906), was found to be as follows: To dimethylamine hydrochloride (1 mol.) was added about one-eighth its weight of water and considerable ether. The flask was cooled and powdered caustic potash (2.5 mol.) added. A solution of bromcyanogen (1 mol.) in three times its weight of ether was then added in portions, the contents of the flask, kept cold by ice water, being well shaken between the additions. When the bromcyanogen had all been added, the ethereal layer was removed and, after the addition of calcium chloride to remove water and a little potassium cyanide to remove any excess of bromcyanogen, the ether was distilled off from the solution and the impure dimethylcyanamide fractionated. Eighty per cent of the dimethylamine hydrochloride taken was changed into the cyanamide desired. The conditions essential for a good yield seem to be a low temperature, a small amount of water, some excess of caustic potash, and dilute solutions of the substances reacting in ether.

ether and the resulting extracts discarded. The aqueous solution was then treated with 100 cc. ether and solid caustic potash until no more would dissolve. Some cooling of the vessel was necessary during the addition of the caustic potash. The extraction of the saturated caustic potash solution with ether was repeated twice more and the combined ether extracts, after drying with solid caustic potash, distilled at reduced pressure.

Methyl dimethylisourea boils at 60.5° (27 mm.), 86° (98 mm.), and, with slight decomposition, at 146.5° (755 mm.). This is about 38° lower than the unsubstituted mother substance, $\text{NH}_2\text{C}(\text{:NH})\text{OCH}_3$.¹ Density of a not quite entirely pure specimen at 16.5° , referred to water at 4° , was 0.9708 (Westphal). Exposure to the air produced no apparent change except that due to evaporation.

Titration with 0.1 N hydrochloric acid and methyl orange gave slightly low results, but perhaps as close as could be expected considering the nature of the substance. In order to avoid loss by evaporation the weighing was made in a glass bulb and a glass bottle used for the titration, the bulb, after the addition of water, methyl orange, and a part of the acid, being broken with a heavy glass rod. 0.2405 gram required 23.09 cc. and 0.1295 gram required 12.38 cc. 0.1 N acid; calculated for $\text{C}_4\text{H}_{10}\text{ON}_2$, 23.55 cc. and 12.67 cc.

Its concentrated water solution gives the skin the same soapy feeling as a solution of potassium hydroxide. When dissolved in a little water there is a distinct heat evolution which would lead to the inference that, like methyl dipropylisourea, it is more soluble in cold than in warm water. However I was not able, by heating the concentrated (1:2 and 1:1) water solutions, to bring about a separation of the base as a distinct layer which would disappear on cooling, and thus verify this inference.

A water solution of the isourea dissolves silver oxide and aluminium hydroxide but not cupric hydroxide. With a solution of mercuric chloride it gives a white precipitate soluble in an excess of the isourea, and with mercurous nitrate

¹ Stieglitz and McKee: Ber. d. chem. Ges., **33**, 1518 (1900).

a black precipitate similar in appearance to that given by ammonia. The nature of these salts has not been determined.

Action of Water on Methyl Dimethylisourea.—In general it may be stated that, at 100° , the reaction with water gave exclusively dimethylurea and methyl alcohol and no trace of the corresponding urethane or cyanamide. At room temperature the action was slow and there was, in addition to the same products as were formed at 100° , some evidence of the formation of a trace of dimethylurethane or dimethylcyanamide. The experimental portion, which follows, was made as nearly quantitative as possible.

The solution (1:2) of the isourea in water, when titrated with standard acid, was found to contain 0.323 gram of the isourea in each cubic centimeter. Two cc. of this solution in a sealed tube were heated in a boiling water bath for two hours. The tube opened with no pressure and the odor of the isourea was still plain. Titration of 1 cc. required 11.43 cc. of 0.1 N acid for neutrality. This would correspond to 0.118 gram of the unchanged isourea remaining in 1 cc. of the solution.¹ The end point, with methyl orange as the indicator, was quite definite, thus showing that neither dimethylcyanamide, $(\text{CH}_3)_2\text{NCN}$, nor dimethylurethane, $(\text{CH}_3)_2\text{N.COOCCH}_3$, were present in appreciable amounts. Separate experiments have shown that dimethylcyanamide and dimethylurethane give indefinite end points with methyl orange and 0.1 N acid.

To the remainder (1 cc.) of the solution was added an excess of an alcoholic solution of picric acid, the tube cooled to 10° , and the precipitate filtered off and dried on a porous plate. It weighed 0.40 gram and melted at 133° alone and when mixed with the synthetic dimethylurea picrate.² The filtrate from the dimethylurea picrate had a volume of 4.5 cc., of which all except 1 cc. was alcohol. A solubility determination showed that 100 parts dilute alcohol (70 per cent) containing a little

¹ Possibly this alkalinity is due in part to ammonia and dimethylamine formed by hydrolysis (cf. page 13) of the dimethylurea, but with the short time of heating, this factor is so very small that it has been disregarded.

² Zand [Rec. Trav. Chim., 8, 224 (1889)] describes α,α dimethylurea picrate as melting at 130° , but I found that, if carefully prepared and not washed too much on the filter (water readily hydrolyzes the salt) it melts at 133° .

picric acid dissolves about 4 parts dimethylurea picrate, or 0.18 gram for the 4.5 cc. of the filtrate. This amount (0.18 gram) added to the weight of the picrate precipitate (0.40 gram) obtained above corresponds to 0.187 gram methyl dimethylisourea. This added to the unchanged isourea found by titration (0.118 gram) gives 0.305 gram which is, within the limit of error of the measurements, the weight of the isourea taken (0.323 gram) in each cubic centimeter.

When the action of water at room temperature was studied it was found that with a solution of the same strength the reaction was the same in general character as at 100° but required about a month for half completion. At the end of a month the titration with tenth-normal acid and methyl orange required one more drop of acid for the completion of the color changes at the neutrality point than it should have done if nothing but methyl alcohol and dimethylurea had been formed. Evidently there had been formed a trace of a slightly basic substance like dimethylcyanamide or more probably, judging from the analogies between the isoureas and imidoethers,¹ dimethylurethane. Dimethylcyanamide would be formed by the loss of alcohol from the isourea molecule, and dimethylurethane by the addition of water and the loss of ammonia. With the quantities of material at hand I was not able to suggest a method by which the trace of the slightly basic substance could be isolated and completely identified.

Methyl Dimethylisourea Hydrochloride, $(\text{CH}_3)_2\text{N}.\text{C}(:\text{NH})\text{OCH}_3.\text{HCl}$, was prepared by adding dry hydrogen chloride to a cold solution of methyl dimethylisourea in either absolute ether or ligroin. The salt first separated as an oil but by scratching with a glass rod this was caused to crystallize in four-sided needles. The salt was dried *in vacuo* over caustic potash and concentrated sulphuric acid. Analyses for chlorine showed 25.52 and 25.56 per cent; calculated for $\text{C}_4\text{H}_{11}\text{ON}_2\text{Cl}$, 25.58 per cent. Heated rapidly it melted at 91° with gas evolution and the residue in

¹ McKee: THIS JOURNAL, 26, 258 (1901). Pinner, Die Imidoäther und ihre Derivate (1892), pages 6 and 7.

the melting point tube solidified and on further heating remelted at 174° – 175° .¹

The hydrochloride must be handled very quickly for it takes up moisture from the air as rapidly as fused calcium chloride. It is very soluble in all the ordinary solvents except ether and ligroin. Attempts to recrystallize it by the addition of ether, or ligroin, to its concentrated alcoholic solution, or to a solution in chloroform, were all without success.

A nearly pure sample of the hydrochloride was kept in a desiccator over concentrated sulphuric acid and solid potassium hydroxide for some months. By titration of weighed amounts from time to time with silver nitrate it was found that there was a steady loss of chlorine—in eight months the percentage of chlorine decreased from 25.5 to 3.4 per cent. A careful examination of the material left after eight months' standing by precipitating the concentrated aqueous solution with alcoholic picric acid, according to the method earlier used,² showed that the amount of dimethylurea present exactly accounted for the weight of material taken, if allowance were made for an amount of the unchanged isourea hydrochloride corresponding to the 3.4 per cent chlorine found still present in the material. In other words the reaction at room temperature is fairly rapid and is *exclusively* a decomposition into dimethylurea and methyl chloride.

The identity of the dimethylurea picrate obtained above was made certain by its melting point (133°)³ and by titration with 0.1 N alkali and phenolphthalein. 0.5766 gram required 18.09 cc. sodium hydroxide; calculated for $C_9H_{11}O_8N_5$, 18.17 cc.

Stability of Methyl Dimethylisourea.—Pinner has shown⁴ that the imidoethers slowly decompose at room temperature, and more quickly on heating, into the nitrile and alcohol from which they were originally prepared. With the isoureas no similar decomposition has been detected. I now find that an

¹ Franchimont [Rec. Trav. Chim., 3, 222 (1884)] gives the melting point of the asymmetrical dimethylurea as 180° .

² Page 25.

³ Footnote, page 25.

⁴ Loc. cit.

analogous decomposition actually takes place in a few cases.¹

Three and nineteen-hundredths grams methyl dimethylisourea were heated in a sealed tube at 100° for 50 hours. The tube opened with no pressure. A small amount of a solid insoluble in ether had separated. The amount of this solid was so small (0.07 gram) that its identification was not found to be practicable.

Some of the oil, after decantation from the solid, was dissolved in dilute acid and the resulting solution half distilled. The distillate gave a strong test for methyl alcohol when treated with a hot copper spiral and resorcinol.² A parallel test with the original isourea did not give this reaction for methyl alcohol.

Titration of 0.2452 gram of the oil required 21.11 cc. 0.1 N acid; calculated for the unchanged isourea, 24.00 cc. The neutrality point to methyl orange was not sharp, indicating that dimethylcyanamide, a weak base, had been formed according to the equation



Owing to the closeness of their boiling points, their great volatility with ether vapor, and the similarity of their solubilities, it is not possible to separate a small amount of dimethylcyanamide from the isourea. An indirect proof of its presence was obtained by preparing more of the isourea from it and determining the amount of the methyl dimethylisourea formed by the increased alkalinity. This was accomplished by mixing some of the oil, in which it was desired to show the presence of dimethylcyanamide, with a little of a three-fourths normal solution of sodium methylate in methyl alcohol, titrating 1 cc. with standard acid, heating for an hour at 45°, and then titrating again. The increase in alkalinity was due to the formation of methyl dimethylisourea from the dimethylcyanamide and accounted for more than two-thirds of the discrepancy between the acid used, 21.11 cc., and the calculated amount, 24.00 cc., in the first-mentioned titration of the oil.

¹ But not in all cases; cf. page 22.

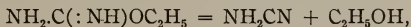
² Mulliken and Scudder: *THIS JOURNAL*, **21**, 266 (1889).

A parallel experiment with ethyl isourea, $\text{NH}_2\text{C}(:\text{NH})\text{OC}_2\text{H}_5$, showed that the decomposition is very much more rapid but entirely analogous to that just described for the dimethylisourea, except that there is a polymerization of one of the primary products of the reaction. Ethyl isourea heated at 100° for 2.5 hours in a sealed tube gave much solid mixed with a little liquid. The filtrate largely boiled at 78° and gave the iodoform test for ethyl alcohol. Ethyl isourea does not give the iodoform reaction.

The solid after crystallization from hot water was analyzed by titration with 0.1 N hydrochloric acid and methyl orange. 0.1610 gram required 12.24 cc., 0.1028 gram required 7.90 cc.; calculated for melamine, $(\text{NH}_2\text{CN})_3$, 12.76 cc. and 8.15 cc. The point of neutrality of the titration was uncertain to about 0.10 cc. of the acid used. That it was melamine was made entirely certain by its solubilities and by the fact that by heating it in a dry tube it gave at low heat a white sublimate and at a higher temperature ammonia gas and a yellow residue (mellon).

A test for dicyandiamide¹ showed that substance to be present in small amounts. Parallel experiments showed that neither the isourea nor the melamine give this violet color with copper sulphate.

The reaction at 100° seems then to be a decomposition of the isourea according to the equation



and then the customary polymerization of the unstable cyanamide to form some dicyandiamide, $(\text{NH}_2\text{CN})_2$, but principally melamine, $(\text{NH}_2\text{CN})_3$.

The study of these compounds is being continued.

LAKE FOREST COLLEGE,
LAKE FOREST, ILLINOIS;
April 20, 1909.

¹ Bamberger and Seeberger; Ber. d. chem. Ges., 26, 1587 (1893).

[Contributions from the Sheffield Laboratory of Yale University.]

CLXVII.— RESEARCHES ON PYRIMIDINES:
THE PREPARATION OF 3-METHYL- AND 3-
BENZYLURACIL.

[FORTY-THIRD PAPER.]

BY HENRY L. WHEELER AND TREAT B. JOHNSON.

From a theoretical standpoint a larger number of alkyl compounds may result by alkylating a uracil derivative than can be obtained by a similar treatment of a 2-mercapto-6-oxypyrimidine. With the mercaptopyrimidines only three mono-derivatives should result. With uracil, 4-methyluracil, thymine, or 5-methyluracil, in each case there are ten possible compounds, four mono- and six dialkyl derivatives. This includes oxygen derivatives, but not tautomeric forms. In the case of the 2-amino-6-oxypyrimidines, the guanidine derivatives, the alkylation may be still more complicated.

The work done in this laboratory has therefore been confined almost entirely to the alkylation of mercaptopyrimidines. 2-Ethylmercapto-6-oxypyrimidine¹ and 2-ethylmercapto-5-ethoxy-6-oxypyrimidine² gave with potassium hydroxide and methyl iodide the 1-methyl derivatives in largest quantity, while 2-ethylmercapto-5-methyl-6-oxypyrimidine³ gave a mixture of about equal amounts of the 1- and 3-methylated products. 2-Ethylmercapto-5-ethoxy-6-oxypyrimidine⁴ with benzyl chloride also gave a 1-benzyl derivative as the chief product.

On the other hand 2-ethylmercapto-6-oxypyrimidine⁵ and 2-ethylmercapto-5-methyl-6-oxypyrimidine gave mostly 3-alkyl compounds with benzyl chloride. A similar result was obtained with the former pyrimidine and ethyl chloracetate.⁶

Besides the N isomers there were probably formed, in most of these cases, some 6-oxyalkyl derivatives (oils), the amount

¹ Johnson and Heyl: *THIS JOURNAL*, **37** 628 (1907).

² Johnson and Jones: *Ibid.*, **40**, 538 (1908).

³ Johnson and Clapp: *J. Biol. Chem.*, **5**, 51 (1908).

⁴ Johnson and Jones: *Loc. cit.*

⁵ Johnson and Derby: *THIS JOURNAL*, **40**, 444 (1908).

⁶ Wheeler and Liddle: *J. Am. Chem. Soc.*, **30**, 1152 (1908).

of 6-oxy derivative being noteworthy in the methylation of 2-anilino-6-oxypyrimidine.¹

These examples show that no regularity is observed in the alkylation of 2-mercapto-6-oxypyrimidines, that analogous salts can give different results with the same halide, and that with different halides the salts may be attacked in different positions. It will also be noticed from the above that the papers so far published have contained accounts only of the results obtained with 2-mercapto-6-oxypyrimidines. It was therefore of interest to study the alkylation of some isomeric 2-oxy-6-mercaptopyrimidines and to examine the effect produced when the mercapto group and the oxygen atom were interchanged.

We now find when 2-oxy-6-methyl-mercaptopyrimidine (V.) is treated with potassium hydroxide, in alcoholic solution, and either methyl iodide or benzyl chloride, that 3-alkyl derivatives result. The amount of isomeric products, if any, formed in this reaction is very small.

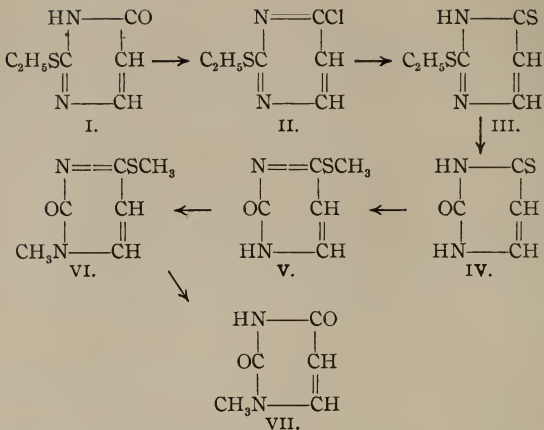
The 6-mercapto derivatives, like the 2-mercapto compounds, on boiling with hydrochloric acid evolve mercaptan and pass smoothly into uracil derivatives. The new 3-methyluracil (VII.) thus obtained now completes the list of the theoretically possible monomethyluracils. It gives no color with diazobenzenesulphonic acid although the isomeric 1-methyluracil gives a red coloration.²

2-Oxy-6-methylmercaptopyrimidine (V.) was prepared by methylating 6-thiouracil (IV.), while the preparation of the latter substance has been described by Wheeler and Liddle.³ The various steps in the synthesis of 3-methyluracil may be represented as follows:

¹ Johnson and Heyl: *THIS JOURNAL*, **38**, 238 (1907).

² Johnson and Clapp: *J. Biol. Chem.*, **5**, 163 (1908)

³ *THIS JOURNAL*, **40**, 547 (1908).



3-Methyluracil dissolves in alkali and is precipitated unaltered by hydrochloric acid.

Müller¹ obtained a 3-methyluracil-4-carboxylic ester, by condensing oxalacetic ethyl ester and methylurea. When the sodium salt of this substance was treated with hydrochloric acid he obtained β -methyluramidoacrylic acid, $\text{H}_2\text{N} - \text{CO} - \text{N}(\text{CH}_3)\text{CH} = \text{CHCOOH}$. Neither acids nor alkalies changed this substance into 3-methyluracil.

Similar peculiar relations have been observed before in the pyrimidine series. Fischer and Roeder² in their synthesis of uracil obtained an acid which differed from uracil by one molecular proportion of water. It was left undecided whether this substance was uracilic acid (Uracilsäure), $\text{H}_2\text{N} - \text{CO} - \text{NHCH} = \text{CHCOOH}$, or oxyhydrouracil,

$\overline{\text{HN} - \text{CO} - \text{NH} - \text{CH}_2 - \text{CHOHCO}}$. They did not succeed in converting the substance into uracil.

Johnson and Clapp³ obtained two α -methyl- β -guanidineacrylic acids. One could be dissolved in dilute alkali and be

¹ J. prakt. Chem., **56**, 498 (1897).

² Ber. d. chem. Ges., **34**, 3760 (1901).

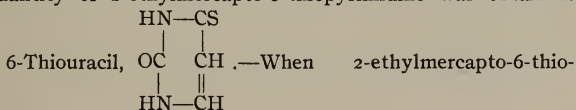
³ THIS JOURNAL, **32**, 130 (1904).

reprecipitated by acids unaltered, with the other this treatment closed the ring and gave 2-amino-5-methyl-6-oxy-pyrimidine. The explanation given for the existence of these two acids was that they represented the *cis* and *trans* modifications.

Such an explanation might also account for the fact that—like Müller's pyrimidines—certain uracil derivatives dissolve in alkali and on precipitating with acids give the corresponding uramidoacrylic acids, while others—such as our 3-methyl-uracil—are precipitated in the form having the closed, uracil ring.

EXPERIMENTAL PART.

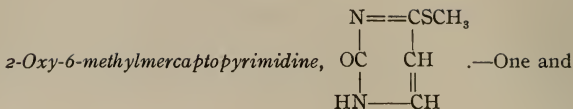
The preparation of 2-ethylmercapto-6-thiopyrimidine from 2-ethylmercapto-6-chlorpyrimidine¹ has been described by Wheeler and Liddle.² In the present work instead of employing two and a half times the calculated quantity of potassium hydrosulphide we have taken four times the calculated amount. By this method a yield of over 90 per cent of the calculated quantity of 2-ethylmercapto-6-thiopyrimidine was obtained.



pyrimidine is treated with concentrated hydrochloric acid the pale yellow color of the compound changes to a bright yellow. If water is added the color disappears or becomes much lighter. If this solution is boiled too long the material is completely desulphurized and uracil is obtained. The following procedure, however, gave a yield of over 90 per cent of the calculated amount of 6-thiouracil: Nine and six-tenths grams of 2-ethylmercapto-6-thiopyrimidine were added to a mixture of 50 cc. of concentrated hydrochloric acid and 50 cc. of water. On warming, mercaptan was evolved and solution took place, then 6-thiouracil separated. The acid was evaporated on the steam bath and the residue was crystallized from water.

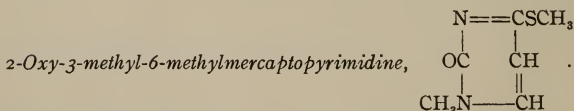
¹ Wheeler and Johnson: THIS JOURNAL, **29**, 496 (1903); **31**, 596 (1904).

² *Ibid.*, **40**, 555 (1908).



one-tenth grams of sodium were dissolved in 25 cc. of methyl alcohol and 6.1 grams of 6-thiouracil were added. The mixture became semisolid owing to the separation of a colorless, difficultly soluble sodium salt. Ten grams of methyl iodide and 25 cc. more methyl alcohol were added. On warming the mixture, solution soon took place and it then gave a neutral reaction. The alcohol was evaporated and the residue was treated with water. Crystalline material separated which, after washing with water and drying, weighed 5 grams, or 73.7 per cent of the calculated. This dissolved easily in hot water and on cooling, long, slender needles or prisms were obtained melting to an oil with no effervescence at 205°.

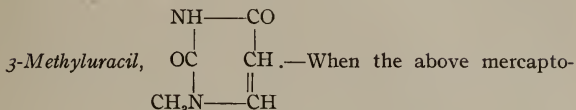
	Calculated for $\text{C}_6\text{H}_6\text{ON}_2\text{S}$.	Found.
N	19.71	19.50



—Four and four-tenths grams of sodium were dissolved in 100 cc. of absolute alcohol and then 10.5 grams of 6-thiouracil were added. On warming a clear solution resulted. The solution was then cooled and 28 grams of methyl iodide were added. A mass of colorless crystals consisting of the sodium salt of 2-oxy-6-methylmercaptopyrimidine separated. On adding 100 cc. more of alcohol and warming for a few hours a clear solution that had a neutral reaction was again obtained. The alcohol was then evaporated off, the final portions in a vacuum. The product was separated from sodium iodide by repeated extractions with chloroform. When about 9.5 grams of material had been extracted it was purified by crystallizing from benzene. It separated in needles which melted at 124° to a clear oil without effervescence.

It was very soluble in cold water, alcohol, chloroform, and boiling ethyl acetate.

N	Calculated for $C_6H_8ON_2S$.	Found.
	17.95	17.76



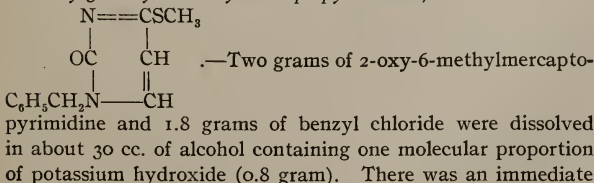
pyrimidine was boiled with strong hydrochloric acid mercaptan was readily given off and on evaporating the acid under diminished pressure colorless prisms were obtained. The crude product melted at 223° – 226° while 1-methyl uracil melts at 174° – 175° .¹

The material was very soluble in water and boiling alcohol. It crystallized from absolute alcohol in rectangular prisms and from hot saturated, aqueous solutions in needles which melted at 232° to an oil without effervescence. It gave no red color with diazobenzenesulphonic acid in presence of sodium hydroxide. With bromine water and barium hydroxide it gave a purple precipitate. 3-Methyluracil is less soluble in cold water than 1-methyluracil.

N	Calculated for $C_8H_8O_2N_2$.	Found.
	22.22	21.90

Some of the above material was dissolved in cold dilute sodium hydroxide and the solution carefully neutralized with dilute hydrochloric acid. The pyrimidine was recovered unaltered and melted at 232° .

2-Oxy-3-benzyl-6-methylmercaptopyrimidine,



¹ Johnson and Heyl: THIS JOURNAL, **37**, 633 (1907).

reaction when the mixture was heated and potassium chloride separated. The solution was warmed on the steam bath until it gave no alkaline reaction. The potassium chloride was then filtered off and the solution was cooled, whereupon the benzyl derivative separated in prisms melting at 148° – 149° to an oil without effervescence. This melting point was not raised by recrystallizing from alcohol. The alcohol filtrates were evaporated to dryness on the steam bath and the residue was treated with dilute sodium hydroxide to remove any unaltered material. The insoluble portion melted without further purification at 146° – 148° and was practically pure 3-benzyl derivative. The yield of this pyrimidine was 2.9 grams, or 90 per cent of the calculated. No evidence of the formation of an isomeric benzyl derivative was obtained.

	Calculated for $C_{12}H_{12}ON_2S$.	Found.
N	12.06	12.19

When this mercaptobenzylpyrimidine was boiled with hydrochloric acid it gave a quantitative yield of 3-benzyluracil¹ melting at 172° – 173° . A mixture of this compound and a sample of 3-benzyluracil melted at 172° – 173° , while a mixture of the pyrimidine in question and 1-benzyluracil (m. p. 175°) melted at 140° – 145° .

Action of Methyl Iodide on 2-Ethylmercapto-6-oxypyrimidine.—We have reexamined the action of methyl iodide on the potassium salt of 2-ethylmercapto-6-oxypyrimidine² and we now find that both 1- and 3-methyl derivatives are formed. In the previous work only the 1-methyl derivative was isolated. A mixture of 2-ethylmercapto-6-oxypyrimidine (15.2 grams), potassium hydroxide (5.6 grams), and methyl iodide (18 grams), in 75 cc. of alcohol was warmed on the steam bath until the solution gave a neutral reaction. It was then evaporated to a syrup and a little water was added. This caused the separation of 3.6 grams of 1-methyl-2-ethylmercapto-6-oxypyrimidine which was filtered off. The filtrate was boiled with hydrochloric acid and evaporated to dryness and the

¹ Johnson and Derby: *THIS JOURNAL*, **40**, 444 (1908).

² Johnson and Heyl: *Loc. cit.*

residue was repeatedly extracted with boiling alcohol. The part insoluble in alcohol proved to be uracil. The alcoholic solution was decolorized with animal charcoal and some sulphur dioxide. The alcohol was evaporated and the residue was fractionally crystallized from water. We then obtained the 3-methyluracil melting at 232° and the 1-methyl derivative melting at 174° . Owing to their similar solubility in alcohol, water, and other solvents it is impossible to make even an approximately quantitative separation by this treatment. It seems to us, however, that the 1-methyl derivative is formed in largest quantity. Further work may show that these proportions vary with change of conditions.

NEW HAVEN, CONN.,
April, 1909.

CONDUCTIVITY AND VISCOSITY IN MIXED SOLVENTS CONTAINING GLYCEROL.

BY M. R. SCHMIDT AND HARRY C. JONES.

[ELEVENTH COMMUNICATION.]

PART I.

This investigation is the latest in a series which has been carried out in the Physical Chemical Laboratory of the Johns Hopkins University, dealing with the relations between electrical conductivity and viscosity of solutions of various electrolytes in certain nonaqueous solvents, and in mixtures of these solvents with water and with each other. The results of the first seven investigations have been published as Monograph No. 80, of the Carnegie Institution of Washington, 1907. Since that time an eighth communication by Jones and Veazey¹ has appeared, and a ninth, by Jones and Mahin,² is about to be published. It now seems desirable to bring together the more important facts thus far established and the conclusions drawn from them.

Previous Work in Nonaqueous Solvents.

The modern theory of solutions has been largely based on

¹ Z. physik. Chem., **62**, 44 (1908).

² To appear in Z. physik. Chem., 1909, Jubelband zu Arrhenius.

experimental work done in aqueous solutions, but lately an increasing amount of attention has been given to the behavior of solutions in solvents other than water; and the present work has to deal with certain questions that presented themselves in connection with solutions in methyl and ethyl alcohols, acetone, and mixtures of these solvents with water and with one another.

Considerable work had already been done on solutions in these solvents, and a few measurements had been made of solutions in mixtures. Carrara¹ carried out an extensive investigation, using methyl alcohol as the solvent, and studying the electrical conductivity of a great variety of salts. Zelinsky and Krapivin² also worked with solutions in methyl alcohol, and with a few in a mixture of methyl alcohol and water. This work will be referred to again.

Hartwig,³ Vicentini,⁴ Cattaneo,⁵ and Völlmer⁶ have determined the conductivity of a great variety of salts in ethyl alcohol. A few measurements have been made in some of the higher alcohols by Schlamp,⁷ Carrara,⁸ and Kablukoff.⁹ Cattaneo¹⁰ and Carrara¹¹ also published the results of a good deal of work in acetone. The work of Dutoit and Aston,¹² as well as that of Dutoit and Friderich,¹³ should be mentioned here. Dutoit and Aston formulated the hypothesis that the dissociating power of a solvent is a direct function of its degree of association in the pure state. This relation has been found to hold for a large number of cases, but there are many and important exceptions to it, and its value has often been overestimated.

By far the largest and most important work on organic

¹ Gazz. Chim. Ital., **26** [1], 119 (1896).

² Z. physik. Chem., **21**, 35 (1896).

³ Wied. Ann., **33**, 58 (1888); **43**, 838 (1891).

⁴ Beibl. Wied. Ann., **9**, 131 (1885).

⁵ *Ibid.*, **18**, 219, 365 (1894).

⁶ Wied. Ann., **52**, 328 (1894).

⁷ Z. physik. Chem., **14**, 272 (1894).

⁸ Gazz. Chim. Ital., **27** [1], 221 (1897).

⁹ Z. physik. Chem., **4**, 432 (1889).

¹⁰ Rend. R. Accad. Linc. [5], **4**, 2 sem., 63.

¹¹ *Loc. cit.*

¹² Compt. Rend., **125**, 240 (1897).

¹³ Bull. Soc. Chim. [3], **19**, 321 (1897).

solvents is the series of investigations carried out by Walden and his students.

Ten papers¹ have appeared from his laboratory, dealing with the relations between conductivity and viscosity, dielectric constants, refractive indices, solvent power, etc., for about thirty organic solvents.

Mixed Solvents.

Wakeman² made an extensive investigation with aqueous ethyl alcohol, finding that the conductivity of organic acids in it decreased with increasing amounts of alcohol. Zelinsky and Krapivin³ obtained the interesting result that the conductivity of sodium and ammonium bromides and iodides in aqueous methyl alcohol containing 50 per cent alcohol is less than the conductivity in either the alcohol or the water. Wakeman found from his results that the equation

$$\frac{\Delta}{p(100 - p)} = \text{constant}$$

held satisfactorily for many substances in mixtures of ethyl alcohol and water, Δ being the difference between the conductivity of the electrolyte in water and in the mixture, and p the percentage of alcohol by volume.

Cohen⁴ found the relation

$$\frac{\mu_v \text{H}_2\text{O}}{\mu_v \text{H}_2\text{O. Alc.}} = \text{constant}$$

to hold independently of temperature and concentration.

Conductivity and Viscosity.

Wiedemann⁵ was the first to point out a connection between conductivity and viscosity. From his work on solutions of copper sulphate, he formulated a relation

$$\frac{k\gamma}{p} = \text{constant},$$

¹ Z. physik. Chem., **46**, 103; **54**, 129; **55**, 207; **55**, 281, 683; **58**, 479; **59**, 192; **59**, 385; **60**, 87; **61**, 633.

² *Ibid.*, **11**, 49 (1893).

³ *Loc. cit.*

⁴ Z. physik. Chem., **25**, 31 (1898).

⁵ Pogg. Ann., **99**, 229 (1856).

where k is the conductivity of a solution of concentration p , and γ is its viscosity.

Stephan¹ showed that in alcohol and water mixtures the temperature coefficients of conductivity and fluidity were nearly the same. He also found a minimum conductivity in certain mixtures.

For a complete discussion of the electrochemistry of non-aqueous solutions, one should consult Carrara's "Elettrochimica delle soluzioni non aqueose"² which covers the literature well up to the year 1906.

Experimental.

The work of Jones and his assistants comprises a uniform series of investigations, the same experimental methods being used in each. The conductivities were determined by the ordinary Kohlrausch method. The bridge wire, resistance boxes, thermometers, etc., were all calibrated or tested against the same standard instruments. Measurements were made at two temperatures, 0° and 25°.

The conductivity water was purified by the method of Jones and Mackay,³ and had a mean conductivity at 0° of 1×10^{-6} , and twice that amount at 25°. The alcohols were purified by careful distillations after being boiled with lime several times. The conductivity of the ethyl alcohol was between 0.2×10^{-6} and 2×10^{-6} , and that of the methyl alcohol was about the same as that of the water. The acetone was dried by calcium chloride, and had an average conductivity of about 0.6×10^{-6} .

Viscosity measurements were made by means of the Ostwald viscometer.⁴

The work of Thorpe and Rodger⁵ was consulted for the values of the viscosity of water at 0° and 25°.

The standard of conductivity is, in all cases, that of a fiftieth-normal solution of potassium chloride at 25°, which is taken as 129.7 reciprocal Siemens's units.

¹ Wied. Ann., **17**, 673 (1883).

² Gazz. Chim. Ital., **37** [1], 1 (1907); Ahrens' Sammlung, **12**, 11 (1908).

³ THIS JOURNAL, **19**, 91 (1897).

⁴ Phys.-chem. Mess., 2nd. Ed., p. 260.

⁵ Phil. Trans., **185**, A, 307 (1894).

Jones and Lindsay undertook a further investigation of the phenomenon observed by Zelinsky and Krapivin, and by Cohen, namely, a minimum value of conductivity in a fifty per cent mixture of methyl alcohol and water. The solvents used were methyl, ethyl, and *n*-propyl alcohols, water, and binary mixtures of these liquids. The electrolytes studied were potassium, cadmium, and strontium iodides, ammonium bromide, and lithium nitrate. In every case it was found that the molecular conductivity of solutions in the mixed solvents was less than the average calculated from the conductivities in the components. In some cases, curves with well-defined minima were obtained at 0°, some of which persisted at 25°, while others developed into sagging curves with no minima.

As a partial explanation of these facts, this tentative suggestion was made:

It is known that water and the alcohols are highly associated substances, that is, their molecules in the liquid state exist as complexes, the composition of which varies with the temperature. Now, according to the hypothesis of Dutoit and Aston, only those substances which are associated can dissociate molecules. Hence, water and the alcohols, on coming in contact, lower the state of association of each other, until a condition of equilibrium is reached. The mixture, being now less associated than its components, should have less dissociating power than the latter, and this is actually the case in every instance studied. Moreover, the lowering of conductivity is more marked when the alcohols are mixed with water than when they are mixed with each other, because they are associated to a less degree than water.

This conclusion was subsequently confirmed by Jones and Murray.¹ By means of cryoscopic measurements with water, formic and acetic acids, and mixtures of these liquids, they showed that the molecular weights of these substances were always less, even in very concentrated solutions, than the values obtained by Ramsay and Shields, who had found that these liquids are all highly associated in the pure condition.

¹ THIS JOURNAL, 30, 193 (1903).

Jones and Carroll¹ extended the work of Jones and Lindsay. The solvents used were water, methyl and ethyl alcohols, and various mixtures of these with one another. The electrolytes chosen were cadmium iodide, sodium iodide, calcium nitrate, hydrochloric acid, sodium acetate, and potassium iodide. Cadmium iodide in mixtures of methyl alcohol and water showed no minimum, except in the curves for $V = 16$, $V = 32$, and $V = 64$ at 0° . Here a minimum appeared in the 75 per cent mixture. In all cases, however, the conductivities were less than the average values. In mixtures of ethyl alcohol and water, the same salt showed entirely similar phenomena, though no minima were observed. Sodium iodide gave a well-defined minimum in the 50 per cent mixture of methyl alcohol and water. Calcium nitrate in the same solvents gave no minimum, while the conductivities again did not obey the law of averages. Hydrochloric acid gave irregular results, but a minimum was noticed in a mixture containing 90 per cent methyl alcohol. Sodium acetate in various mixtures of acetic acid and water gave entirely irregular figures.

An effort was made to determine the dissociating power of the methyl alcohol-water mixtures, since it had been noticed that the molecular conductivity, μ_v , for hydrochloric acid became constant at rather small dilutions in these solvents. Limiting values of conductivity were obtained for sodium, potassium, and ammonium iodides and bromides, and lithium nitrate, in 50 per cent methyl alcohol. In all these cases, the dissociation was complete in the mixture at a dilution considerably less than that necessary for complete dissociation in water or methyl alcohol. It now remained to find the cause of the minimum.

Two factors are to be considered, amount of dissociation, and ionic mobility. The first has been eliminated, hence the minimum must be caused by a decrease in ionic mobility. From the results of various observers, it was found that the viscosity of aqueous alcohol in the neighborhood of a 50 per cent mixture is higher than that of either of its constituents.

¹ THIS JOURNAL, 32, 521 (1904).

Furthermore, the change in viscosity with increasing content of alcohol is more marked at low temperatures than at higher, and rise in temperature shifts the maximum in viscosity, or minimum in fluidity, slightly towards the mixture containing the greater percentage of alcohol. These phenomena are closely paralleled by the conductivity minima. The latter all occur in or near the 50 per cent mixtures, and are more marked at 0° than at 25° . Cadmium iodide, for instance, shows a minimum at 0° in three solutions, but none at 25° . Potassium iodide, strontium iodide, and lithium nitrate give minima in the 50 per cent mixture at 0° , which move to the 75 per cent mixture at 25° .

A method was then devised for comparing the variations in fluidity and conductivity, and for studying the effect on conductivity of changes in fluidity. The differences between the (calculated) average values and the observed conductivities and fluidities in the various mixtures were expressed in percentages, and in all cases the variation in fluidity was found to be greater than the variation in conductivity. Letting

$\Delta\phi$ and $\Delta\mu_v$ represent the two variations, then $\frac{\Delta\phi - \Delta\mu_v}{\Delta\phi}$

represents the relative effect of variation in fluidity on conductivity. If the two effects are equal, the expression becomes equal to zero. It was found that in the 40 per cent mixtures, the effect of change in fluidity on conductivity is greatest. Finally, the temperature coefficients of conductivity and of fluidity were not found to differ markedly; in other words, $\frac{\mu_v}{\phi}$ is nearly a constant.

Jones and Carroll therefore conclude that the decrease in conductivity in binary mixtures is due primarily to a decrease in the fluidity of the solvent, and, consequently, a decrease in the ionic mobility, and secondarily to the effect of one associated solvent on the association of another.

A quantitative study of the relation between the conductivity and viscosity of different solutions was then made. In order that data for different solvents might be comparable, measurements were made with "comparable equivalent solu-

tions," that is, solutions containing the same number of gram-molecules of electrolyte in the same number of gram-molecules of solvents. The result was that the conductivities of such solutions were found to be inversely proportional to the viscosity of the solvent, and directly proportional to the association factor of the solvent, or to the amount of dissociation of the electrolyte in that solvent. Otherwise expressed,

$$\frac{\mu_v \eta}{x} = \text{constant or } \frac{\mu_v \eta}{\alpha} = \text{constant.}$$

The work of Bassett¹ showed that silver nitrate, in mixtures of methyl alcohol and ethyl alcohol with water, presented phenomena entirely in accord with the observations of Jones and Lindsay and of Jones and Carroll. The conductivity curves for ethyl alcohol-water solutions fall far below the straight line of averages, but give no minima; the methyl alcohol-water curves, on the other hand, give well-marked minima at both 0° and 25°, the variation from the average being more pronounced at the lower temperature.

Jones and Bingham² introduced another solvent into the investigation, namely, *acetone*. The electrolytes studied were lithium nitrate, potassium iodide, and calcium nitrate, and quite unexpected results were obtained. Lithium nitrate, in mixtures of acetone and water, gave curves with an inflection point at low dilutions and at 0°, which developed minima in the higher dilutions at 0°. The conductivity curves for solutions in mixtures of methyl and ethyl alcohols with acetone gave *maxima*, which, in the higher dilutions, occurred always in the mixtures containing 75 per cent acetone. The curves are very nearly straight lines below this point, but drop rapidly to the values in 100 per cent acetone. This fact is important in connection with the work of Mahin, to be considered later. Potassium iodide in mixtures of the alcohols with acetone gave conductivity curves which were very nearly straight lines, either slightly convex or concave towards the axis denoting percentages of acetone. In mixtures of acetone

¹ THIS JOURNAL, **32**, 409 (1904).

² *Ibid.*, **34**, 481 (1905).

and water, the same salt gave pronounced minima in the neighborhood of the 50 per cent mixtures. Calcium nitrate in mixtures of methyl and ethyl alcohols with acetone gave curves with maxima at both 0° and 25°. In mixtures with water, the results were again irregular. In the first place, the values of μ_v for calcium nitrate in acetone are surprisingly small, less than those for lithium nitrate or potassium iodide, although it is a ternary electrolyte. In consequence, the curves for acetone-water mixtures, at dilutions greater than $V = 400$, reach a minimum in the 50 per cent mixture, and rise to the 75 per cent mixtures—in this point resembling the curves for potassium iodide—but thereafter sink to the small values on the ordinate representing 100 per cent acetone.

The viscosity measurements brought to light the facts that the fluidity curves of mixtures of the alcohols with acetone are nearly straight lines, while the acetone-water mixtures give a minimum fluidity in the 50 per cent mixture. In general, therefore, the relation found by Jones and Carroll holds for mixtures containing acetone, that is, there exists a parallelism between the conductivity and fluidity curves. However, the maximum conductivity obtained with solutions of calcium and lithium nitrates in mixtures of acetone with the alcohols demands explanation. Two possible causes suggest themselves at once.

First, there may be an increase in dissociation in the 75 per cent mixtures, where the maximum occurs. Secondly, there may be an increased mobility of the ions, due to a diminution in the size of the ionic spheres. The idea of ionic spheres, proposed by Kohlrausch and by Jones, postulates the existence of an atmosphere of solvent molecules clustered about the ion. To decide between these two possibilities, we may first consider the increase in dissociation. The fluidity data show that the acetone-alcohol mixtures are not more associated than the pure solvents; hence, using Dutoit and Aston's hypothesis, we should not expect to find greater dissociation in the mixtures. Moreover, while it is true that the maximum conductivity occurs in the 75 per cent mixture, this is true only for dilute solutions, the maximum shifting to the 25

per cent mixture as the concentration increases. This would not occur if the 75 per cent mixture had the greatest dissociating power. Therefore, the tentative view is accepted, that the maximum in conductivity is due to a change in the dimensions of the ionic spheres, and a consequent increase in migration velocity.

The conclusion of Dutoit and Friderich, and of Jones and Carroll, that conductivity is proportional to dissociation and inversely proportional to viscosity, must be supplemented by taking into consideration the possible changes in the size of the ionic spheres of solvent molecules.

Jones and Rouiller¹ undertook the study of silver nitrate. This salt gave results practically identical with those obtained by Jones and Bingham for lithium and calcium nitrates. The conductivity curves for acetone-water mixtures gave inflection points in the higher concentrations, and a pseudo-maximum in the 75 per cent mixture, the value of the molecular conductivities declining rapidly, however, to the figures for pure acetone. The curves for mixtures of methyl and ethyl alcohols are nearly straight lines, following the fluidity curves; and maxima are found in the acetone-alcohol curves.

The investigation was extended by McMaster² in a study of lithium bromide and cobalt chloride. The former behaved normally in all the mixtures of the alcohols and water; that is to say, a minimum was noticed in the conductivity curves at 0° and 25° in mixtures of the alcohols with water, while the results for mixtures of the two alcohols obeyed the law of averages almost exactly. In mixtures containing acetone, relations were found very closely analogous to those obtained by Bingham in the case of lithium nitrate. The solutions in alcohol-acetone gave maxima of conductivity in the 75 per cent acetone mixture; while the solutions in water gave minima at the higher dilutions and inflection points at the lower dilutions. The unusual behavior of the acetone mixtures is here again very evident.

Cobalt chloride, on the other hand, gave unexpected re-

¹ THIS JOURNAL, **36**, 427 (1906).

² *Ibid.*, **36**, 325 (1906).

sults. In the first place, the conductivity of its solutions in ethyl alcohol is surprisingly low, being only about 15 per cent as great as in water. In ethyl alcohol-water mixtures, cobalt chloride gave an inflection point in nearly all the solutions, but in the curves for $V = 200$ to $V = 1600$, at 0° , the value of μ_v is greater in the 75 per cent than in the 50 per cent mixture, thereafter declining to the lower values in pure ethyl alcohol. Exactly the same phenomenon is shown by calcium nitrate in acetone-water solutions, where the curves rise from the 50 per cent to the 75 per cent mixture, and drop off rapidly in pure acetone. Rouiller found similar results for silver nitrate. In methyl alcohol-water solutions, cobalt chloride is normal, giving pronounced minima in the 50 or 75 per cent mixtures. Methyl alcohol-ethyl alcohol solutions gave nearly straight lines, as did also solutions in acetone-methyl alcohol. In the last cases the fluidity curves are also nearly straight lines, but the acetone-methyl alcohol conductivity curves have a slope which is the reverse of the fluidity curve. Acetone and ethyl alcohol gave a maximum in the 25 per cent mixture.

In most of the above cases, we see that the conductivity varies directly as the fluidity, and fluidity minima are usually accompanied by conductivity minima. The converse, that conductivity minima were accompanied by fluidity minima, was not always found to be true, as, for instance, with cobalt chloride in acetone-ethyl alcohol. Here a maximum of conductivity is found in mixtures giving a fluidity curve which differs by less than experimental error from a straight line. Again, the conductivity curves for acetone-water show inflection points, while the fluidity curve has a minimum. These apparently irregular results are to be considered again in the work of Jones and Mahin.

In explanation of the minimum of conductivity, Jones and McMaster adopt the view that the diminution in the fluidity of the solvent is an important factor in determining the conductivity minimum. But this does not account entirely for the phenomenon. The change in the size of the ionic sphere, the atmosphere surrounding the ion, must also be considered. The velocity of the ion depends not only

on its composition, but also on its attraction for the solvent.

There yet remain for consideration the several maxima of conductivity noticed in this work as well as in that of Bingham. The discussion of the latter work has shown that it is improbable that the maxima are due to an increase in dissociating power in the mixture where they occur. Moreover, an examination of the conductivities of lithium bromide and cobalt chloride shows that complete dissociation is more nearly reached in the pure solvents than in the mixtures where the maxima are found. Hence, it was concluded that the cause of the effect is primarily a change in the dimensions of the ionic spheres.

Some points of interest were noted in connection with the temperature coefficients of conductivity and of fluidity. First, in nearly every case the temperature coefficients of conductivity are greater in the more dilute than in the more concentrated solutions. The work of Jones has shown that in practically all solutions there is some combination between solvent and solute, and that the solvates become more complex as the dilution increases. Therefore, change in temperature, which affects the complex solvates most, has a greater effect on the conductivity of the more dilute solutions.

A second point worth noting was that in certain solutions negative temperature coefficients of conductivity were found. These manifested themselves in solutions of cobalt chloride in acetone, in 75 per cent acetone and methyl alcohol, and in 50 and 75 per cent acetone and ethyl alcohol. In the 75 per cent acetone and methyl alcohol, when $V = 200$, the temperature coefficient is *zero*.

The change in conductivity with temperature is the algebraic sum of two opposing influences. First, rise in temperature diminishes dissociation; secondly, rise in temperature is accompanied by an increase in fluidity. The first of the processes tends to decrease conductivity, the second to increase it. When the sum is positive, we have increasing conductivity with rise in temperature, as is usually found to be the case. In the one instance mentioned above, the two

forces are equal, and the conductivity is independent of the temperature.

The investigation of Jones and Veazey¹ included a study of the behavior of copper chloride and potassium sulphocyanate. Both of these electrolytes gave results which were almost entirely "normal;" that is, conductivity curves followed fluidity curves in every case except two. These exceptions were the curves for copper chloride in mixtures of the alcohols with water. No minima were found here corresponding to the well-marked minimum in fluidity, although the conductivities were always less than required by the law of averages. An inflection point occurs between the 50 and 75 per cent mixtures. The conductivity curves of potassium sulphocyanate show no such irregularity, but are in every respect parallel to the fluidity curves of the solvents.

In addition to determining the fluidities of the various solvent mixtures, Jones and Veazey measured the fluidities of solutions of potassium sulphocyanate in these mixtures. It was found that in many cases the fluidity of the solution is greater than the fluidity of the solvent; in other words, potassium sulphocyanate, under certain conditions, has a negative viscosity coefficient. In mixtures of methyl alcohol and water, the viscosity of the tenth-normal solutions is less than that of the 0, 25, and 50 per cent solvent mixtures, and greater than the 75 per cent mixture, becoming equal at some point corresponding to about 65 per cent alcohol. The same phenomena repeat themselves in ethyl alcohol-water mixtures. With acetone and water, the negative viscosity coefficient again becomes apparent, this time only in the 0 and 25 per cent mixtures. In the other mixed solvents, the viscosity is increased by the addition of the solute.

An examination of the literature relating to viscosity brought to light the important fact that, in general, only salts of potassium, rubidium, and caesium are known to lower the viscosity of water. Very few other cases of negative viscosity have been found, and not all salts of these metals behave alike in this respect. For instance, the sulphate, ferrocyanide, ferri-

¹ THIS JOURNAL, **37**, 405 (1907); Z. physik. Chem., **61**, 641 (1908).

cyanide, and chromate of potassium give positive viscosity coefficients. And it is not remarkable that in the presence of certain anions, the alkali cations do not give negative viscosity coefficients. Viscosity must be considered to be a property which is a function of the nature of all the particles in a solution, and it is perfectly clear that here, as in conductivity, two opposing influences may be operative, the potassium cation, for instance, tending to lower the viscosity and the anion tending to increase it. If the algebraic sum is positive, a positive viscosity results, and *vice versa*, the actual viscosity of the solution being dependent on the relative action of the two ions.

The facts have been presented showing that in aqueous solution, or in solutions containing as much as 50 per cent of water, potassium sulphocyanate produces a lowering of the viscosity. What is the mechanism of this effect?

The work of Thorpe and Rodger has shown that viscosity phenomena are, in all probability, dependent upon the frictional surfaces of the various particles in any solution. If the total frictional surface can be diminished by any means, other factors remaining constant, the viscosity will be lowered. We may actually realize this by bringing into a solvent a substance which has a large molecular volume, or which gives ions having large ionic volumes. The total frictional surface proportional to the mass is thus lessened, since the surface increases as the square of the diameter of the particles, while the mass increases as the cube. Potassium, rubidium, and caesium salts, as we have said, lower the viscosity of water. Are their atomic volumes, accordingly, larger than those of other elements? The periodic curve of atomic volumes answers this question at once. The alkali metals occupy the maxima of the curve, and no other metals have atomic volumes to be compared with them. Moreover, that element having the greatest atomic volume—caesium—should have the greatest negative viscosity coefficient. This point is soon tested by reference to the work of Wagner.¹ If the viscosity of water is taken as unity, a normal solution of caesium chloride lowers

¹ Z. physik. Chem., 5, 35 (1890).

it to 0.9775, a normal solution of rubidium chloride gives 0.9846, and potassium chloride 0.9872. Thus the effect on viscosity varies directly as the atomic volume of the cation, caesium having an atomic volume of 74, rubidium of 57, and potassium 47.

It will be remembered that minima of fluidity were found in mixtures of water with the alcohols or with acetone, accompanied usually by minima in conductivity. The fact also came out that in those mixtures which have the minimum fluidity, the temperature coefficients of conductivity are largest. The explanation of this is sufficiently evident. Each solvent, highly associated in the pure condition, breaks down the association of the other, as shown by Jones and Murray, so that the resulting mixture is composed of a greater number of smaller molecules in a given volume. Simple molecules would probably have greater chemical activity than the more complex ones and would combine with the solute to a greater extent. The effect of heat on such solvates would be greater with increasing complexity of the solvate. In connection with this breaking down of the solvents into simpler aggregates, the total internal frictional surface would be increased, and an increase in viscosity is the result. Again, in terms of Dutoit and Aston's hypothesis, the dissociating power of such a mixture should be less than that of the pure solvents, and this is an important factor in determining the conductivity minimum, as pointed out by Jones and Bingham. It is noticed that in these mixtures of minimum fluidity, there is a smaller increase of conductivity with dilution than in the other mixtures, and this is, of course, a consequence of the view here adopted.

In a second communication,¹ Jones and Veazey took up a study of solutions of tetraethylammonium iodide—Walden's "Normalelektrolyt"—in mixtures of water, the alcohols, and nitrobenzene. The latter is a solvent of a type entirely different from the hydroxy compounds or acetone, and it was important to know whether the relations previously found would hold for mixtures containing this substance.

¹ Z. physik. Chem., **62**, 41 (1908).

In mixtures of both the alcohols with water, tetraethylammonium iodide shows a well-defined conductivity minimum in the neighborhood of the 50 or 75 per cent mixtures at both 0° and 25° . In mixtures of the alcohols with each other, no minima appeared, although the values are less than the averages. Mixtures of methyl alcohol and nitrobenzene behaved similarly, but mixtures of ethyl alcohol and nitrobenzene gave a maximum in the solutions containing 25 per cent of the latter. The fluidity curves of mixtures of water and the alcohols have already been sufficiently treated, and here, as before, the conductivity curves follow them closely. The same general relations appear in mixtures of nitrobenzene and the alcohols. A fluidity maximum shows itself in mixtures containing 25 per cent of nitrobenzene, with either alcohol, and at 0° and 25° . Hence, the conductivity curves, in the case of nitrobenzene-ethyl alcohol mixtures at least, follow the fluidity curves, and the variation with nitrobenzene-methyl alcohol is slight.

It has now been shown that for all the solvents worked with, it is practically a constant phenomenon for conductivity curves to have the same general characteristics as fluidity curves. On the other hand, we must not lose sight of the fact that several well-marked exceptions have been found, and notably in mixtures containing acetone. Here the fluidity curves for water-acetone have minima, and for acetone-alcohol are nearly straight lines, while the conductivity curves for lithium bromide, lithium nitrate, cobalt chloride, and calcium nitrate show pronounced maxima, or pseudomaxima. Moreover, the values of the molecular conductivities in acetone are abnormally low, except for lithium salts.

In the work of Walden,¹ already referred to, it was found that the product of the limiting molecular conductivity of tetraethylammonium iodide and the viscosity of its infinitely dilute solutions is nearly a constant for about thirty organic solvents, and equal to about 0.7. Water and glycol are exceptions, giving products equal to 1.0 and 1.32, respectively. The product $\mu_{\infty} \eta$ is also independent of temperature. There-

¹ Z. physik. Chem., **55**, 207 (1906).

fore, generally speaking, conductivity varies as the fluidity of the solvent. But, as we have shown, in certain solutions containing acetone, this relation no longer holds.

It may further be noted that Jones has shown¹ that cadmium iodide and ammonium sulphocyanate, in acetone solutions, have abnormally high molecular weights, although such solutions conduct the current. He pointed out that these facts indicate simultaneous association and dissociation of the solute; a high concentration of molecular complexes, which causes an abnormal apparent molecular weight, coexisting with a low ionic concentration, which causes a low conductivity value. A consideration of these points suggested to Jones and Mahin several lines of inquiry, which were taken up in the ninth communication.² They sought to answer the following questions:

1. Will those salts that have, at ordinary concentration, abnormally low values for molecular conductivity possess, when completely dissociated, values which are inversely proportional to the coefficient of viscosity?

2. If so, is the product of molecular conductivity and viscosity constant for mixed solvents and at different temperatures?

3. Is the value of the constant the same for different electrolytes?

4. Are the abnormal conductivities in acetone and mixtures of acetone with other solvents due to association of the salt?

The first salt studied was lithium nitrate. Extreme precautions were taken to insure purity of the solvents, and measurements were carried to dilutions as high as 200,000 liters wherever practicable. Under these conditions, the conductivity curves assumed forms which differed markedly from those obtained for dilutions between 10 and 1600 liters, and which closely resembled the fluidity curves. Moreover, the product of the viscosity coefficient and the maximum conductivity in solutions of acetone mixed with the alcohols

¹ THIS JOURNAL, **27**, 16 (1902).

² To appear in *Z. physik. Chem.*, August, 1909.

has a mean value of 0.62, agreeing well with Walden's value of 0.70 for simple solvents, and being independent of temperature. With acetone-water mixtures, the product varies between 1.00, the value for water, and 0.63, the value for acetone.

Some determinations of the molecular weight of lithium nitrate in acetone by the boiling point method brought out interesting results. The concentration of the solutions varied roughly between normal and tenth-normal. Even in the more dilute solutions, the indicated molecular weight was 83.1, while the value required by the formula LiNO_3 is 69.07. This accounts for the low conductivity of lithium nitrate in acetone solutions of not very great dilution.

As already stated, cadmium iodide was found by Jones to be associated in acetone, and a study of this salt was next made. Results in this case were not so satisfactory as with lithium nitrate. The conductivity curves show signs of regaining a similarity to the fluidity curves, but the resemblance is not so close as with the other salt. Moreover, the product of the viscosity by the maximum conductivity is irregular. The conductivity data show that in most cases a limiting value was not reached with cadmium iodide, and some solutions more nearly approached the true values than others, thus causing the fluctuations in the value of the product. It must be borne in mind that conductivity measurements at dilutions so great (400,000 liters) that the correction for the conductivity of the solvent often amounts to more than 50 per cent of the total, are being made at a point where the method is taxed rather beyond its limitations; and it is not surprising that even with the utmost precautions, concordant results are not obtained. The failure of cadmium iodide to follow the behavior of lithium nitrate in very dilute solutions is merely negative evidence, and must be weighed as such.

Some boiling point determinations of cadmium iodide in acetone were made, and here too, considerable polymerization was found. In a 0.09 normal solution, the indicated molecular weight was 448, calculated 364.

Thus, the apparent exceptions to the relations found by Jones and his coworkers are seen to vanish when we are dealing with what are practically infinitely dilute solutions. The investigations have dealt with twelve electrolytes and six solvents, and in every instance the same relations are found to hold, connecting the molecular conductivity with the fluidity.

Jones and Mahin¹ also made a study of the conductivity and viscosity of lithium nitrate in ternary mixtures of the four solvents used above. The results were about what would be expected from a knowledge of the solutions in binary mixtures. The conductivity curves, in the great majority of cases, followed the fluidity curves, and no new relations were brought to light.

As a result of this work, we may make the general statement: If we mix methyl and ethyl alcohols, or methyl alcohol and acetone, the conductivity curves are very close to straight lines, and the fluidities of the mixture are nearly additive. Take, for instance, the last case mentioned. The table shows the fluidities of various mixtures of methyl alcohol with acetone at 0°, as determined by the viscometer, and also as calculated from those of the two components.

Fluidity of Mixtures of Methyl Alcohol and Acetone at 0°.

Per cent acetone	0	25	50	75	100
Fluidity observed	122.2	153.9	187.4	222.2	244.1
Fluidity calc.	...	152.7	183.2	213.7	...

The observed fluidities are very nearly the averages corresponding to the different mixtures. On the other hand, if we mix water with the alcohols, or with acetone, there is interaction between the components of the mixture, and certain of its physical properties are found no longer to bear simple relations to the properties of the single solvents. Otherwise expressed, the law of averages is not followed, and the properties of the mixture are not additive. Hence, we may conclude that water, mixed with the other three solvents, causes some deep-seated change in the state of molecular aggrega-

¹ THIS JOURNAL, 41, 433 (1909).

tion of the liquid molecules, while mixing the three organic solvents with each other causes no such change. The various mixed solvents may therefore be divided into two classes, those not containing water, with properties nearly or quite additive, and those containing water, with properties that are not the averages of the two components.

PART II.

It is thus seen that certain definite relations exist between the conductivity of various electrolytes dissolved in binary mixtures of four solvents, and the viscosity of their solutions. It was of interest to know whether similar relations would hold when one of the component solvents had a viscosity much greater than that of the other; in other words, whether the effect of one solvent on another follows the same laws, no matter what substances are used. The solvent eminently suited for this purpose is glycerol. Not only is its viscosity enormously greater than that of any other homogeneous liquid at ordinary temperatures, but several of its physical constants would lead us to expect glycerol to be well adapted as a solvent in making conductivity measurements. The dielectric constants and association factors of the solvents used in the previous work are given in Table I. The dielectric constants are taken from the work of Drude¹ and were all determined in the neighborhood of 18°, and the association factors are taken from the work of Ramsay and Shields,² and refer to nearly the same temperature.

Table I.

Solvent.	Dielectric constant.	Association factor.
Water	81.7	4.00
Methyl alcohol	32.5	3.43
Ethyl alcohol	21.7	2.74
Acetone	20.7	1.26

Glycerol has a dielectric constant of 16.5 at 18°, and hence, in terms of the Thomson-Nernst rule, should have a fairly high dissociating power. Moreover, if we assume Dutoit

¹ Wied. Ann., **60**, 500.

² Z. physik. Chem., **12**, 433 (1893).

and Aston's hypothesis to hold even approximately for glycerol, the association factor of the latter, 1.80 at 20°, would lead to the same conclusion. The conductivity data will show that these expectations are well founded, and that glycerol is, in all probability, a solvent with a dissociating power rather above the average.

Glycerol as a Solvent.

It has, of course, been known for a long time that glycerol has remarkable solvent properties. Not only will it dissolve all deliquescent salts, such as many compounds of lithium and calcium, but it also takes up large quantities of nearly all the halogen salts of the common metals, including even those which are difficultly soluble in water, as well as many sulphates, nitrates, etc. In addition, the alcohol groups of glycerol react with metallic oxides and hydroxides, forming glycerates by a process analogous to the solution of sodium or potassium hydroxides in alcohol.

In spite of the ease with which very pure glycerol can be obtained in large quantity, very little work has been done with solutions in it. In various branches of manufacture, and especially in pharmacy, it has long had extensive use as a solvent, but no systematic study has been made of the properties of its solutions.

Cattaneo¹ measured the conductivity of a number of halogen salts of the metals in glycerol, and found that the conductivities are smaller than the corresponding values in water or alcohol, but greater than those in ether. He also states that the molecular conductivity increases only in the case of chlorides. This last statement is not at all confirmed by the present work.

Schöttner² carried out an extensive investigation on the viscosity of glycerol and of some of its mixtures with water. Arrhenius³ measured the viscosity of certain organic substances, including glycerol, in aqueous solution, and found that the decrease of η with rising temperature is greatest

¹ Rend. Accad. Linc. [5], 2, II, 112 (1893).

² Wien. Ber., 77, 2, 682 (1878).

³ Z. physik. Chem., 1, 289 (1887).

when η is large. Schall and van Rijn¹ determined the relative times of flow of various mixtures of glycerol with small quantities of water and alcohol.

EXPERIMENTAL.

Conductivity Apparatus.

The conductivity measurements were made by the Kohlrausch method, using a wire bridge and telephone receiver. The bridge wire was calibrated and found to be of uniform resistance throughout. The conductivity cells were of the form used by Jones and Bingham and subsequent workers in this laboratory. For use with the solutions in pure glycerol, two cells of a different type were used. The electrodes in one cell consisted of two concentric platinum cylinders, about 7 cm. long, and 18 and 22 mm. in diameter. They were maintained at a constant distance apart of about 2 mm. by means of several drops of fusion glass attached to the edges of the cylinders. The constant was very low, about 4.30. The other cell had as electrodes three cylinders, the outer and inner being joined by a thick branching platinum wire, and forming one electrode, while the middle cylinder formed the other. Drops of fusion glass also served here to keep the electrodes at a constant distance apart of about 1.5 mm. The cell constant was about 2.35. The electrodes of both cells were used without being covered with platinum black, and it was possible to obtain very sharp minima on the bridge with them. For instance, when the cell contained conductivity water, and a resistance of one or two thousand ohms was introduced into the circuit, the bridge could easily be read at points two mm. on each side of the true minimum. This form of cell has proved itself to be especially adapted to work with very viscous solutions. The large electrode surface permits of the cylinders being several mm. apart, without making the "capacity" of the cell too great; and this feature alone is of great advantage, as it allows very thick liquids to fill all the space between the electrodes, without the danger of imprisoning air bubbles. The escape of the

¹ Z. physik. Chem., **23**, 329 (1897).

latter is further facilitated by the vertical position of the cell walls. The "constants" of both cells showed only extremely slight variation throughout the work.

The conductivity measurements are expressed in reciprocal Siemens's units, and the cell constants were determined by means of a fiftieth-normal potassium chloride solution, the molecular conductivity of which was taken as 129.7 at 25°.

Measurements were made at 25° and 35°. Glycerol, when maintained at 0° for a long period, undergoes a gradual change, resulting sometimes in the deposition of crystals. On this account, and for the reason that at low temperatures the substance is so extremely immobile that viscosity determinations are almost impossible, no measurements were made at 0°, as has been the custom in these investigations. The temperature coefficients of conductivity and viscosity are therefore not strictly comparable with those obtained by other workers for the same solutions between 0° and 25°.

The constant-temperature baths were of the form described before, and were maintained constant within 0°.03 of the desired temperatures. The thermometers were compared with a certificated Reichsanstalt instrument. The measuring flasks were calibrated to hold aliquot parts of the true liter at 20°, and solutions were brought to within 0°.2 of this temperature before filling to the mark.

Solvents.

Glycerol.—The glycerol used was Kahlbaum's "Glycerin, 1.26." Two determinations of different lots gave the same density, $D_{25}^{25} = 1.2586$. The specific conductivity varied from 0.5×10^{-7} to 0.7×10^{-7} at 25°. Some of the glycerol was distilled under diminished pressure, boiling at 160° under a pressure of 6 mm. The specific conductivity was not changed by this process, and the remainder of the glycerol was used without further treatment.

Water.—The water was purified essentially by the method of Jones and Mackay,¹ with a slight modification. The practice heretofore has been to distil ordinary distilled water

¹ THIS JOURNAL, 17, 83 (1895).

from acidified potassium dichromate to destroy organic matter and retain ammonia, and then to redistil from a weaker chromic acid solution, forcing the steam from the second distillation through a solution of barium hydroxide. There can be no doubt that water prepared in this way still contains large quantities of carbon dioxide. The extreme rapidity with which the current of steam passes through the alkaline solution makes it impossible for the latter to come in contact with all of the vapor, and some of the carbon dioxide escapes with the steam to be condensed, giving water with a conductivity which has generally been about 2×10^{-6} at 25° . If, however, the second distillation is made from a solution containing barium hydroxide instead of acidified dichromate, the conductivity of the water is lowered considerably. Nearly all of the carbon dioxide is retained, and the conductivity of the water thus purified has rarely risen over 1.5×10^{-6} , and was many times as low as 1.2. In addition, the alkaline solution, probably owing to the presence of the fine crystals of barium carbonate, boils more quietly than the acid solution, with entire absence of bumping, and with consumption of much less gas.

Ethyl and Methyl Alcohols.—These were purified by boiling the commercial articles with fresh lime for a day, and then distilling again from more lime without transferring the alcohol in the air. A third distillation from lime was made if the specific gravity of the second distillate showed the presence of any appreciable quantity of water. Several more distillations were then made through a block-tin condenser. The conductivity of the ethyl alcohol ranged between 1.2×10^{-7} and 1.8×10^{-7} , although in one case it was as low as 0.9×10^{-7} . The value for the methyl alcohol was about 1.5×10^{-6} at 25° .

Work with mixtures containing acetone, which it was hoped would yield some interesting results, had to be given up, since glycerol and acetone are only slightly miscible.

The mixed solvents are made up on a volume basis, and in every case throughout the work, unless otherwise speci-

fied, "*n* per cent A and B" means *n* cc. of solvent A diluted to 100 cc. with solvent B.

Solutions.

All solutions were made on a volume-normal basis, at 20°, by direct weighing of the anhydrous salts. A tenth-normal mother solution was first made, from which the fiftieth and hundredth-normal solutions were prepared by dilution. The hundredth-normal solution then served as a mother solution for the two-, four-, and eight-hundredth-normal solutions, and from the last named the sixteen-hundredth-normal was prepared. The dilutions were made by means of calibrated flasks and burettes. It was found that if a little time was given, the solutions containing 25 and 50 per cent of glycerol would drain as completely as aqueous solutions, and the same calibration was used for all three. With the 75 per cent solutions, and especially with those in pure glycerol, the draining was incomplete, even though the burette stood two days. Accordingly, a different calibration was made for each of the three mixed solvents containing 75 per cent of glycerol, and for the pure glycerol itself. The amount to be delivered was run at a fixed rate of flow into a weighing glass, and its weight divided by the density of the solvent at 20°. The difference between the volume thus found and the volume read off was the amount clinging to the walls of the burette, and this quantity, which was about 0.60 cc. for 25 cc. of glycerol, was added with each measurement of the solutions. It was of course necessary to run the solutions out between the same two points on the burette each time, as otherwise the mean hydrostatic pressure would vary, causing corresponding variations in the rate of flow, with a marked effect on the amount which did not drain out. This precaution is important, as shown by the fact that a volume of glycerol drawn off between 0 and 25 on the burette lacked 0.65 cc. of 25 cc., while the same apparent volume, taken between 24 and 49, was 0.35 cc. less than the amount desired. The water calibration showed that this difference was not due to a great irregularity in the diameter of the burette. Another point which

must be noted is the necessity of keeping the temperature of the working room very constant while measuring glycerol. The changes in volume of the glycerol are inconsiderable compared with the great changes in fluidity, and a calibration made for 20° would, by reason of the much greater fluidity of glycerol at a higher temperature, be very inaccurate at 22°.

In view of the fact that so little work has been done with solutions in glycerol, a few details of a practical nature may not be out of place. In spite of the great solvent power of glycerol, the actual rate of solution is very slow, and most substances can be dissolved only after a great deal of shaking and heating. It was customary in this work to heat the glycerol to almost 100° before adding it to the salt in the measuring flask. At this temperature, glycerol is quite fluid, and its solvent action is greatly enhanced. Nevertheless, it required, with lithium bromide and cobalt chloride, nearly three hours of practically continuous shaking, with the temperature at about 80°–100°, to effect the complete solution of one or two grams of the salts in 100 cc. of glycerol. Potassium iodide, on the other hand, dissolved as soon as the glycerol was warmed slightly, and gave a clear solution in less than five minutes. In view of the close relation of glycerol to the alcohols, and of the very slight solubility of potassium iodide in absolute alcohol, this behavior is surprising.

Much annoyance is caused by the ease with which glycerol imprisons air bubbles, which may require hours to rise. Especially is this likely to occur when the substance is poured into a burette. This difficulty may be obviated, however, by pouring the solutions in while hot, in which case the air bubbles will rise fairly rapidly; or by pouring the solutions in such a manner that the descending stream does not strike the walls of the burette except at the highest point to which the burette is to be filled. Thus manipulated, the glycerol flows down the burette walls without enclosing any air, and moreover, no time is lost in waiting for the upper part of the burette to drain before taking the initial reading.

Viscosity.

The determinations of viscosity were made by means of

several Ostwald viscometers,¹ or this form as modified by Jones and Veazey.² For the solutions in pure glycerol, as well as for the solutions containing 75 per cent of glycerol, viscometers of very large bore were necessary. Two of these, made for us by Eimer and Amend, were very satisfactory. The small bulb had a capacity of about 4 cc., and the larger of about 30 cc. The "capillaries," having internal diameters of 1.1 and 2 mm., respectively, were 12 cm. long. As the time of flow of water through these viscometers was less than ten seconds, it was of course necessary to calibrate them by using a more viscous liquid, the viscosity of which was known. For this purpose, the viscosities of several solutions, containing about 50 per cent of glycerol, were determined in the smaller instruments, and then the times of flow of these liquids through the large viscometers were noted. A fixed amount of solution was introduced into the viscometer from a pipette, and after being raised to the upper mark by air pressure, was allowed to run through the capillary by its own weight. The times of flow were read with an accurate stopwatch. The viscosities were calculated from the formula

$$\frac{\eta}{\eta_0} = \frac{st}{s_0 t_0},$$

where η_0 , s_0 , and t_0 are the viscosity, density, and time of flow, respectively, of pure water, and η , s , and t the corresponding values for the liquid in question. The values of η_0 at 25° and 35° are taken from Thorpe and Rodger's work³ on viscosity, being 0.00891 at 25° and 0.00720 at 35°. Fluidity, expressed by ϕ , is equal to $\frac{1}{\eta}$, and the temperature coefficients of fluidity are calculated from the formula

$$\text{temp. coef. } \phi = \frac{1}{\phi_{25}} \cdot \frac{\phi_{35} - \phi_{25}}{10}.$$

The densities of the solutions were determined in pycnometers of the form described by Jones and Veazey.²

¹ Phys.-chem. Mess., 2nd Ed., p. 260.

² Z. physik. Chem., **61**, 651 (1908).

³ Phil. Trans., **185**, A, 307 (1894).

The measurement of viscosity, for some reason, seems to be beset with much greater experimental error than would be expected, considering the simple nature of the operation. The values given in Landolt-Boernstein's "Tabellen" often show differences of more than one per cent in the results of various observers. During the present work, it was found to be almost impossible to get results that would agree even fairly well in duplicate determinations. It may at first sight be supposed that by using three "steps" to determine the viscosities of the thicker solutions, as was done in this work, experimental error is introduced at each step, so that the values found by means of instruments with wide capillaries would necessarily be of doubtful accuracy. As a matter of fact, though experimental error is introduced, the departure of the values found from the true values is influenced much less by this fact than by an inherent difficulty in the method.

The Poisseuille formula for determining viscosity is $v = \frac{\pi r^4 p t}{8 l \eta}$, where v is the volume of liquid, whose viscosity coefficient is η , which, under a pressure p , will flow in the time t through tube of length l and radius r . In deriving this formula, the liquid is considered as leaving the tube with a kinetic energy of zero, which, manifestly is an impossible condition in practice. If the liquid flows out of the tube with a positive kinetic energy, a correction must be introduced. On rearranging the formula, with the correction, it becomes

$$\eta = \frac{\pi r^4 p t}{8 v l} - \frac{v d}{8 \pi l},$$

where d is the density of the liquid. In determining viscosities by the relative method—that is, by means of the Ostwald viscometer—the corrected formula is rarely used. For two liquids flowing by their own weight through the same instrument, between the same differences in level,

$$\frac{\eta_1}{\eta_2} = \frac{p_1 t_1}{p_2 t_2}.$$

But

$$\frac{p_1}{p_2} = \frac{\rho_1 g h}{\rho_2 g h} = \frac{\rho_1}{\rho_2},$$

whence $\frac{\eta_1}{\eta_2} = \frac{\rho_1 t_1}{\rho_2 t_2}$, which is the ordinary formula.

It is evident from the corrected formula that when t is smallest, the correction is greatest. Hence, a greater error is introduced by measuring the viscosity of a liquid whose time of flow is much greater than that of the standard, than in the case of one with nearly the same viscosity as the standard. In other words, the error would be a minimum if t could be kept constant. Therefore, the error is kept lowest by using in each instrument liquids whose times of flow do not differ too greatly from t_0 . As the correction is always negative, the viscosity of a liquid determined without using intermediate steps should be greater than if several viscometers are used. This is illustrated in the case of 75 per cent glycerol and methyl alcohol at 25°. T is the time of flow.

Table II.

Viscometer.	T . Water.	T . 50 per cent glycerol and methyl alcohol.	T . 50 per cent glycerol and water.	T . 75 per cent glycerol and methyl alcohol.	η .
A	74.4	749.0	450.0	4465.0	0.61735
1	..	74.7	45.7	445.6	0.6073
2	..	...	...	141.7	0.6073

Here η is calculated by the following methods:

$$\text{For viscometer A. } \eta = \frac{0.00891 \times 4465 \times 1.1546}{1 \times 74.4} = 0.61735$$

(1.1546 is the density of 75 per cent glycerol and methyl alcohol).

For viscometer 1. The viscosities of 50 per cent glycerol and water, and 50 per cent glycerol and methyl alcohol, were determined in A; then from the times of flow of these solutions through 1, two values were obtained which were used to determine viscosities in 1, and the mean value of η for 75 per cent glycerol and methyl alcohol is determined from them, using $T = 445.6$. The same process is employed for viscometer

2. It is seen that η determined by direct comparison with water is greater, as it should be, than η determined by using liquids of intermediate viscosities in several instruments.

Lithium Bromide.

The lithium bromide gave a flame test which showed no appreciable impurity. It was dried to constant weight at 150° , and was again dried after each exposure to the air. Table III. gives the molecular conductivities of lithium bromide in pure glycerol at 25° , 35° , and 45° . It will be noticed that while the values of μ_v are very small, yet they show a regular increase with dilution, as is the case with all liquids having a marked dissociating power.

Table III.—Conductivity of Lithium Bromide in Glycerol at 25° , 35° , and 45° .

V.	$\mu_v 25^\circ$.	$\mu_v 35^\circ$.	$\mu_v 45^\circ$.	Temperature coefficients. $25^\circ-35^\circ$.	Temperature coefficients. $35^\circ-45^\circ$.
10	0.236	0.485	0.907	0.106	0.0871
50	0.260	0.540	1.010	0.107	0.0881
100	0.270	0.555	1.041	0.106	0.0875
200	0.272	0.565	1.050	0.106	0.0868
400	0.275	0.572	1.070	0.108	0.0871
800	0.280	0.579	1.085	0.107	0.0874
1600	0.287	0.593	1.109	0.107	0.0871

Table IV.—Conductivity of Lithium Bromide in Water at 25° and 35° .

V.	$\mu_v 25^\circ$.	$\mu_v 35^\circ$.	Temperature coefficients.
10	91.8	110.7	0.0205
50	101.1	121.9	0.0206
100	103.0	124.4	0.0208
200	105.2	127.4	0.0219
400	107.2	130.1	0.0213
800	114.4	136.1	0.0222
1600	114.6	137.5	0.0200

Table V.—Conductivity of Lithium Bromide in a Mixture of 25 per cent Glycerol and Water at 25° and 35°.

V.	μ_{25° .	μ_{35° .	Temperature coefficients.
10	45.6	57.4	0.0257
50	49.6	62.5	0.0261
100	50.8	64.0	0.0260
200	52.8	66.7	0.0264
400	52.2	65.5	0.0255
800	54.0	69.4	0.0285
1600	54.9	71.5	0.0300

Table VI.—Conductivity of Lithium Bromide in a Mixture of 50 per cent Glycerol and Water at 25° and 35°.

V.	μ_{25° .	μ_{35° .	Temperature coefficients.
10	17.3	23.4	0.0351
50	18.8	25.4	0.0348
100	19.1	25.7	0.0346
200	19.5	26.3	0.0350
400	20.0	27.0	0.0351
800	21.4	28.9	0.0352
1600	21.7	29.5	0.0361

Table VII.—Conductivity of Lithium Bromide in a Mixture of 75 per cent Glycerol and Water at 25° and 35°.

V.	μ_{25° .	μ_{35° .	Temperature coefficients.
10	3.84	5.96	0.0552
50	4.23	6.56	0.0552
100	4.27	6.63	0.0551
200	4.43	6.89	0.0557
400	4.51	6.99	0.0552
800	4.40	6.89	0.0566
1600	4.47	6.99	0.0567

Table VIII.—Conductivity of Lithium Bromide in Ethyl Alcohol at 25° and 35°.

V.	μ_{25° .	μ_{35° .	Temperature coefficients.
10	15.8	18.4	0.0162
50	23.0	26.7	0.0161
100	25.9	30.3	0.0169
200	29.2	33.6	0.0150
400	31.1	36.5	0.0171
800	33.3	39.2	0.0179
1600	35.1	41.6	0.0186

Table IX.—Conductivity of Lithium Bromide in a Mixture of 25 per cent Glycerol and Ethyl Alcohol at 25° and 35°.

V.	μ_{25° .	μ_{35° .	Temperature coefficients.
10	7.26	9.32	0.0283
50	9.49	12.23	0.0289
100	10.00	12.94	0.0294
200	10.93	14.11	0.0291
400	11.21	14.51	0.0294
800	11.68	15.16	0.0298
1600	12.02	15.72	0.0308

Table X.—Conductivity of Lithium Bromide in a Mixture of 50 per cent Glycerol and Ethyl Alcohol at 25° and 35°.

V.	μ_{25° .	μ_{35° .	Temperature coefficients.
10	2.91	4.25	0.0462
50	3.40	4.97	0.0459
100	3.61	5.29	0.0466
200	3.85	5.61	0.0458
400	3.85	5.64	0.0466
800	3.98	5.86	0.0474
1600	4.02	5.89	0.0466

Table XI.—Conductivity of Lithium Bromide in a Mixture of 75 per cent Glycerol and Ethyl Alcohol at 25° and 35°.

V.	μ_{25° .	μ_{35° .	Temperature coefficients.
10	0.947	1.62	0.0710
50	1.08	1.85	0.0711
100	1.14	1.95	0.0719
200	1.14	1.95	0.0718
400	1.19	2.06	0.0720
800	1.18	2.02	0.0713
1600	1.25	2.15	0.0724

Table XII.—Conductivity of Lithium Bromide in Methyl Alcohol at 25° and 35°.

V.	μ_{25° .	μ_{35° .	Temperature coefficients.
10	50.0	56.4	0.0127
50	64.3	72.9	0.0134
100	69.4	78.4	0.0129
200	74.1	84.0	0.0134
400	77.4	87.4	0.0129
800	79.9	89.7	0.0124
1600	81.9	93.1	0.0137

Table XIII.—Conductivity of Lithium Bromide in a Mixture of 25 per cent Glycerol and Methyl Alcohol at 25° and 35°.

V.	$\mu_v 25^\circ$.	$\mu_v 35^\circ$.	Temperature coefficients.
10	21.3	25.8	0.0214
50	25.5	30.9	0.0210
100	27.1	32.9	0.0213
200	28.9	35.3	0.0222
400	29.2	35.7	0.0221
800	30.3	36.8	0.0215
1600	31.2	38.3	0.0226

Table XIV.—Conductivity of Lithium Bromide in a Mixture of 50 per cent Glycerol and Methyl Alcohol at 25° and 35°.

V.	$\mu_v 25^\circ$.	$\mu_v 35^\circ$.	Temperature coefficients.
10	7.34	9.94	0.0350
50	8.44	11.41	0.0353
100	8.86	11.98	0.0352
200	9.21	12.48	0.0355
400	9.49	12.87	0.0356
800	9.59	13.05	0.0361
1600	9.90	13.44	0.0357

Table XV.—Conductivity of Lithium Bromide in a Mixture of 75 per cent Glycerol and Methyl Alcohol at 25° and 35°.

V.	$\mu_v 25^\circ$.	$\mu_v 35^\circ$.	Temperature coefficients.
10	1.73	2.78	0.0607
50	2.01	3.21	0.0599
100	2.13	3.38	0.0584
200	2.30	3.38	0.0470
400	..	..	..
800	2.20	3.55	0.0614
1600	2.17	3.49	0.0626

Table XVI.—Conductivity of Cobalt Chloride in Glycerol at 25°, 35°, and 45°.

V.	$\mu_v 25^\circ$.	$\mu_v 35^\circ$.	$\mu_v 45^\circ$.	Temperature coefficients.	
				25°–35°.	35°–45°.
10	0.270	0.546	1.003	0.1023	0.0836
50	0.369	0.744	1.373	0.1015	0.0846
100	0.391	0.784	1.450	0.1004	0.0780
200	0.455	0.911	1.691	0.1004	0.0857
400	0.473	0.959	1.779	0.1027	0.0855
800	0.497	1.005	1.856	0.1011	0.0847
1600	0.519	1.040	1.920	0.1002	0.0846

Table XVII.—Conductivity of Cobalt Chloride in Water at 25° and 35°.

V.	$\mu_{v25^{\circ}}$.	$\mu_{v35^{\circ}}$.	Temperature coefficients.
10	168.9	204.7	0.0212
50	195.5	236.8	0.0212
100	204.2	246.7	0.0205
200	212.6	256.5	0.0207
400	219.4	267.9	0.0217
800	226.6	276.9	0.0222
1600	232.6	282.6	0.0216

Table XVIII.—Conductivity of Cobalt Chloride in a Mixture of 25 per cent Glycerol and Water at 25° and 35°.

V.	$\mu_{v25^{\circ}}$.	$\mu_{v35^{\circ}}$.	Temperature coefficients.
10	79.9	100.1	0.0252
50	92.6	116.4	0.0258
100	97.6	122.9	0.0259
200	101.7	128.4	0.0262
400	105.3	133.1	0.0264
800	108.5	136.6	0.0260
1600	110.2	139.7	0.0267

Table XIX.—Conductivity of Cobalt Chloride in a Mixture of 50 per cent Glycerol and Water at 25° and 35°.

V.	$\mu_{v25^{\circ}}$.	$\mu_{v35^{\circ}}$.	Temperature coefficients.
10	28.8	38.7	0.0346
50	33.7	45.4	0.0346
100	35.4	47.6	0.0346
200	37.1	49.7	0.0340
400	38.1	51.2	0.0344
800	39.4	53.3	0.0352
1600	40.4	54.5	0.0349

Table XX.—Conductivity of Cobalt Chloride in a Mixture of 75 per cent Glycerol and Water at 25° and 35°.

V.	$\mu_{v25^{\circ}}$.	$\mu_{v35^{\circ}}$.	Temperature coefficients.
10	5.72	8.82	0.0542
50	6.93	10.64	0.0536
100	7.30	11.22	0.0536
200	7.69	11.87	0.0543
400	7.94	12.22	0.0540
800	8.42	12.95	0.0538
1600	8.33	12.75	0.0531

Table XXI.—Conductivity of Cobalt Chloride in Ethyl Alcohol at 25° and 35°.

V.	$\mu_{v25^{\circ}}$	$\mu_{v35^{\circ}}$	Temperature coefficients.
10	4.71	4.96	0.0053
50	9.19	9.05	—0.0017
100	12.18	11.92	—0.0021
200	15.71	15.54	—0.0011
400	19.56	19.64	0.0004
800	24.07	24.91	0.0034
1600	28.78	30.38	0.0056

Table XXII.—Conductivity of Cobalt Chloride in a Mixture of 25 per cent Glycerol and Ethyl Alcohol at 25° and 35°.

V.	$\mu_{v25^{\circ}}$	$\mu_{v35^{\circ}}$	Temperature coefficients.
10	5.43	6.70	0.0233
50	8.13	10.10	0.0243
100	9.30	11.52	0.0239
200	10.66	13.25	0.0243
400	12.14	15.01	0.0236
800	13.89	17.28	0.0244
1600	15.55	19.39	0.0246

Table XXIII.—Conductivity of Cobalt Chloride in a Mixture of 50 per cent Glycerol and Ethyl Alcohol at 25° and 35°.

V.	$\mu_{v25^{\circ}}$	$\mu_{v35^{\circ}}$	Temperature coefficients.
10	2.63	3.77	0.0436
50	3.65	5.11	0.0400
100	4.12	5.78	0.0402
200	4.66	6.53	0.0403
400	5.14	7.32	0.0424
800	5.65	8.03	0.0423
1600	5.86	8.46	0.0443

Table XXIV.—Conductivity of Cobalt Chloride in a Mixture of 75 per cent Glycerol and Ethyl Alcohol at 25° and 35°.

V.	$\mu_{v25^{\circ}}$	$\mu_{v35^{\circ}}$	Temperature coefficients.
10	0.953	1.58	0.0652
50	1.29	2.11	0.0638
100	1.41	2.32	0.0650
200	1.58	2.63	0.0662
400	1.69	2.81	0.0666
800	1.89	3.14	0.0660
1600	1.89	3.20	0.0662

Table XXV.—Conductivity of Cobalt Chloride in Methyl Alcohol at 25° and 35°.

V.	μ_{v25° .	μ_{v35° .	Temperature coefficients.
10	41.9	44.7	0.0066
50	64.6	69.6	0.0077
100	75.6	82.5	0.0098
200	88.9	94.6	0.0065
400	102.2	110.4	0.0080
800	118.1	126.8	0.0078
1600	132.5	144.6	0.0092

Table XXVI.—Conductivity of Cobalt Chloride in a Mixture of 25 per cent Glycerol and Methyl Alcohol at 25° and 35°.

V.	μ_{v25° .	μ_{v35° .	Temperature coefficients.
10	19.6	23.0	0.0173
50	27.8	32.6	0.0172
100	32.1	37.7	0.0175
200	36.6	43.1	0.0176
400	40.7	48.2	0.0185
800	44.8	53.4	0.0192
1600	48.8	57.4	0.0179

Table XXVII.—Conductivity of Cobalt Chloride in a Mixture of 50 per cent Glycerol and Methyl Alcohol at 25° and 35°.

V.	μ_{v25° .	μ_{v35° .	Temperature coefficients.
10	7.64	10.01	0.0310
50	10.22	13.64	0.0334
100	11.64	15.37	0.0323
200	12.84	17.07	0.0330
400	14.11	18.77	0.0330
800	14.99	20.17	0.0346
1600	15.41	20.88	0.0355

Table XXVIII.—Conductivity of Cobalt Chloride in a Mixture of 75 per cent Glycerol and Methyl Alcohol at 25° and 35°.

V.	μ_{v25° .	μ_{v35° .	Temperature coefficients.
10	1.90	3.00	0.0577
50	2.55	3.99	0.0569
100	2.81	4.43	0.0577
200	3.12	4.95	0.0589
400	3.55	5.36	0.0600
800	3.51	5.63	0.0606
1600	3.59	5.76	0.0606

Table XXIX.—Conductivity of Potassium Iodide in Glycerol at 25°, 35°, and 45°.

V.	μ_{v25° .	μ_{v35° .	μ_{v45° .	Temperature coefficients. 25°–35°.	Temperature coefficients. 35°–45°.
10	0.291	0.607	1.189	0.1087	0.0844
50	0.326	0.667	1.275	0.1045	0.0912
100	0.324	0.670	1.257	0.1068	0.0875
200	0.334	0.687	1.284	0.1056	0.0870
400	0.338	0.686	1.282	0.1030	0.0871
800	0.346	0.708	1.325	0.1048	0.0871
1600	0.352	0.717	1.326	0.1039	0.0849

Table XXX.—Conductivity of Potassium Iodide in Water at 25° and 35°.

V.	μ_{v25° .	μ_{v35° .	Temperature coefficients.
10	125.6	150.4	0.0189
50	131.6	156.5	0.0189
100	133.6	159.3	0.0192
200	135.8	162.1	0.0193
400	137.2	163.7	0.0193
800	138.9	165.9	0.0194
1600	140.0	167.5	0.0196

Table XXXI.—Conductivity of Potassium Iodide in a Mixture of 25 per cent Glycerol and Water at 25° and 35°.

V.	μ_{v25° .	μ_{v35° .	Temperature coefficients.
10	61.5	76.6	0.0244
50	64.3	80.1	0.0246
100	65.4	81.7	0.0249
200	66.9	83.4	0.0249
400	67.0	83.9	0.0251
800	68.1	85.2	0.0252
1600	68.7	86.0	0.0252

Table XXXII.—Conductivity of Potassium Iodide in a Mixture of 50 per cent Glycerol and Water at 25° and 35°.

V.	μ_{v25° .	μ_{v35° .	Temperature coefficients.
10	23.9	30.8	0.0289
50	24.4	32.3	0.0327
100	24.6	32.8	0.0333
200	24.9	33.2	0.0332
400	25.1	33.4	0.0336
800	25.4	34.1	0.0340
1600	25.5	34.5	0.0351

Table XXXIII.—Conductivity of Potassium Iodide in a Mixture of 75 per cent Glycerol and Water at 25° and 35°.

V.	$\mu_{v25^{\circ}}$	$\mu_{v35^{\circ}}$	Temperature coefficients.
10	4.94	7.66	0.0552
50	5.13	7.98	0.0555
100	5.25	8.18	0.0559
200	5.14	8.01	0.0559
400	5.42	8.50	0.0569
800	5.48	8.56	0.0563
1600	5.20	8.02	0.0545

Table XXXIV.—Conductivity of Potassium Iodide in Ethyl Alcohol at 25° and 35°.

V.	$\mu_{v25^{\circ}}$	$\mu_{v35^{\circ}}$	Temperature coefficients.
10	21.6	24.8	0.0146
50	28.5	32.7	0.0148
100	31.9	36.9	0.0156
200	35.4	41.5	0.0171
400	37.9	44.5	0.0173
800	40.8	48.1	0.0177
1600	42.6	50.3	0.0179

Table XXXV.—Conductivity of Potassium Iodide in a Mixture of 25 per cent Glycerol and Ethyl Alcohol at 25° and 35°.

V.	$\mu_{v25^{\circ}}$	$\mu_{v35^{\circ}}$	Temperature coefficients.
10	9.50	12.27	0.0291
50	11.35	14.68	0.0293
100	12.12	15.79	0.0303
200	12.88	16.87	0.0309
400	13.40	17.56	0.0310
800	13.99	18.33	0.0310
1600	14.62	18.70	0.0278

Table XXXVI.—Conductivity of Potassium Iodide in a Mixture of 50 per cent Glycerol and Ethyl Alcohol at 25° and 35°.

V.	$\mu_{v25^{\circ}}$	$\mu_{v35^{\circ}}$	Temperature coefficients.
10	3.87	5.67	0.0466
50	4.31	6.31	0.0466
100	..	..	..
200	4.66	6.93	0.0484
400	4.78	7.03	0.0470
800	4.96	7.29	0.0471
1600	4.98	7.28	0.0460

Table XXXVII.—Conductivity of Potassium Iodide in a Mixture of 75 per cent Glycerol and Ethyl Alcohol at 25° and 35°.

V.	$\mu_{v25^{\circ}}$.	$\mu_{v35^{\circ}}$.	Temperature coefficients.
10	1.19	2.05	0.0723
50	1.19	2.11	0.0770
100	1.33	2.28	0.0717
200	1.39	2.37	0.0707
400	1.42	2.43	0.0709
800	1.46	2.51	0.0709
1600	1.49	2.50	0.0700

Table XXXVIII.—Conductivity of Potassium Iodide in Methyl Alcohol at 25° and 35°.

V.	$\mu_{v25^{\circ}}$.	$\mu_{v35^{\circ}}$.	Temperature coefficients.
10	65.5	72.9	0.0114
50	79.6	89.1	0.0120
100	84.0	94.1	0.0121
200	90.9	102.1	0.0122
400	94.8	106.6	0.0125
800	98.0	111.2	0.0134
1600	100.8	113.4	0.0125

Table XXXIX.—Conductivity of Potassium Iodide in a Mixture of 25 per cent Glycerol and Methyl Alcohol at 25° and 35°.

V.	$\mu_{v25^{\circ}}$.	$\mu_{v35^{\circ}}$.	Temperature coefficients.
10	26.4	32.2	0.0219
50	30.6	37.3	0.0220
100	31.8	38.6	0.0218
200	33.3	40.5	0.0217
400	34.2	41.9	0.0224
800	35.3	43.0	0.0218
1600	35.7	44.1	0.0233

Table XL.—Conductivity of Potassium Iodide in a Mixture of 50 per cent Glycerol and Methyl Alcohol at 25° and 35°.

V.	$\mu_{v25^{\circ}}$.	$\mu_{v35^{\circ}}$.	Temperature coefficients.
10	9.15	12.5	0.0366
50	10.2	13.9	0.0365
100	10.4	14.2	0.0363
200	10.8	14.8	0.0364
400	11.1	15.1	0.0363
800	11.5	15.6	0.0364
1600	11.8	16.1	0.0364

Table XLI.—Conductivity of Potassium Iodide in a Mixture of 75 per cent Glycerol and Methyl Alcohol at 25° and 35°.

V.	$\mu_{25^{\circ}}$.	$\mu_{35^{\circ}}$.	Temperature coefficients.
10	2.08	3.41	0.0635
50	2.28	3.68	0.0619
100	2.39	3.90	0.0635
200	2.35	3.82	0.0624
400	2.40	3.90	0.0631
800	2.56	4.27	0.0663
1600	2.46	4.07	0.0648

Tables IV. to XV. show the conductivities of lithium bromide in various mixtures of glycerol with water, methyl alcohol, and ethyl alcohol. The results are plotted in Figures I., II., and III. The curves show that the conductivities in the mixtures depart widely from the law of averages, there being a marked sagging of the curves in each case. The results are much like those obtained by Jones and Carroll with cadmium iodide in mixtures of water and methyl alcohol. No minimum is observed, nor, indeed, has any minimum appeared in all the work with glycerol solutions. This is not surprising. It is hardly probable that any mixture of glycerol with the less viscous solvents would have a viscosity greater than that of pure glycerol. It is conceivable, however, that a mixture of glycerol with a very small percentage of water or alcohol might give a slight minimum in fluidity, but the difficulty of determining this point would be very great. At the same time, a similar minimum in the conductivity curves might make its appearance, and the parallelism of the two sets of curves, which is one of the points to be established, would not be changed, even if minima were found. At any rate, it is evident that in the case of mixtures of glycerol with the other three solvents used, we have to deal with mixtures of the second class referred to above; that is, mixtures whose properties are not additive.

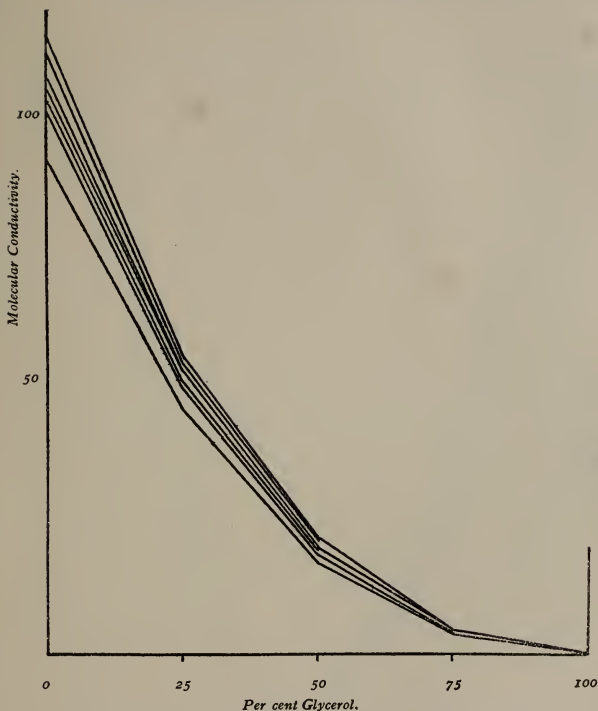


Fig. I.—Conductivity of Lithium Bromide in Glycerol-Water at 25°.

Cobalt Chloride.

The cobalt chloride was first crystallized from conductivity water, to free it from traces of sulphates. The crystallization was continued until the mother liquor no longer clouded barium chloride solution. The salt was then partially dehydrated in a vacuum desiccator, with sulphuric acid, after which it was pulverized, and heated in the air till it had assumed a lavender color. After being again pulverized, it

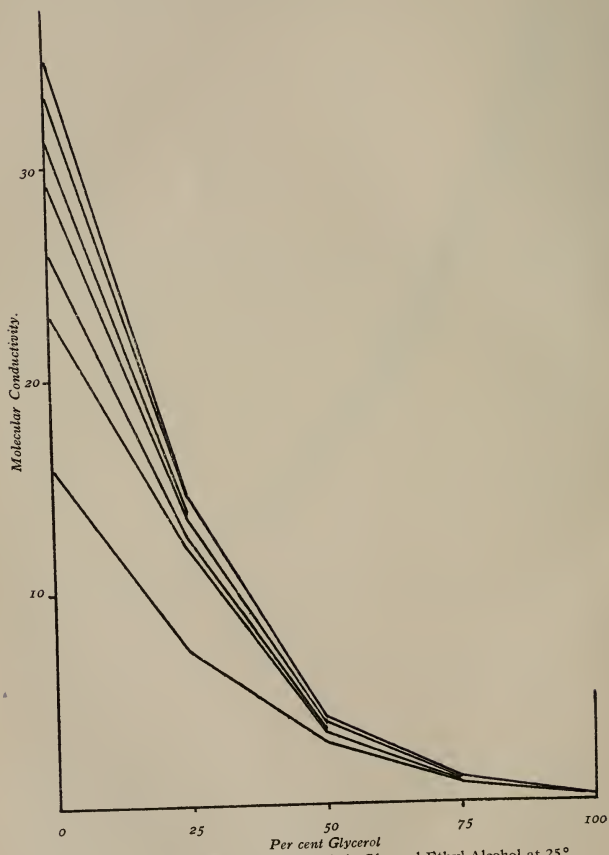


Fig. II.—Conductivity of Lithium Bromide in Glycerol-Ethyl Alcohol at 25°.

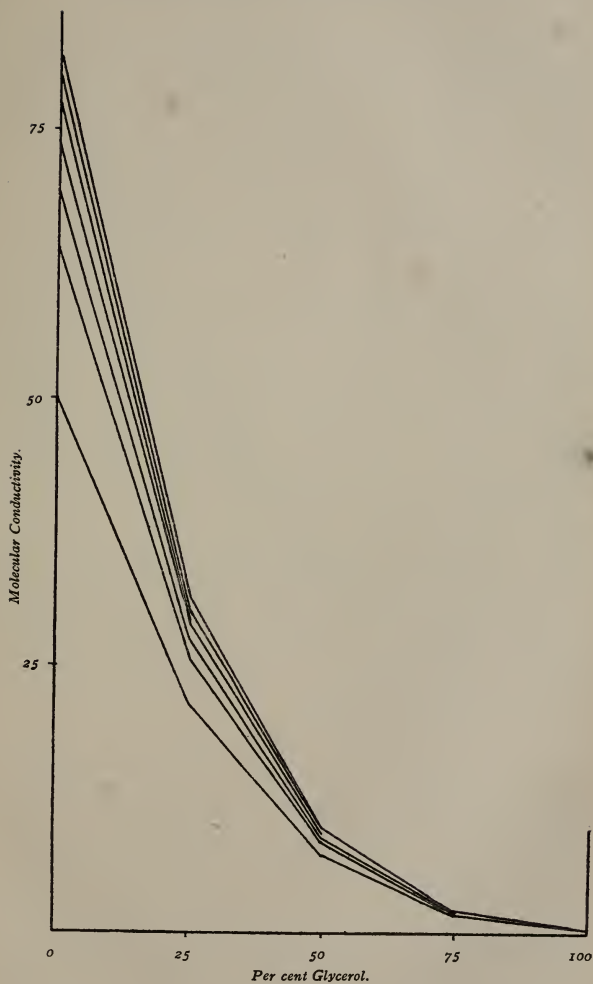


Fig. III.—Conductivity of Lithium Bromide in Glycerol-Methyl Alcohol at 25°.

was placed in a hard-glass tube, and heated in a current of dry hydrochloric acid gas for several hours at 250° , during which process it changed color to a pale pure blue. The hydrochloric acid gas was then replaced by a stream of nitrogen dried over phosphorus pentoxide, and the tube allowed to cool slowly. The cobalt chloride gave a clear solution in water, which, however, when exposed to sunlight, deposited a very small quantity of a flocculent brown precipitate. Not enough of this could be obtained for a complete examination. It did not contain iron, and did not give the reactions of bivalent cobalt. It is thought to be a cobaltic compound, produced by some oxidizing action brought about by the sunlight. Solutions kept in the dark did not show this precipitate, even when allowed to stand overnight; but ten minutes' exposure to bright sunlight was sufficient to cause the change. For this reason, the conductivities of cobalt chloride in aqueous solution are considered a little uncertain, and are probably a little too high. Solutions in the alcohols and in glycerol were perfectly clear, and remained so indefinitely, sunlight having no effect on them.

The conductivities of cobalt chloride are given in Tables XVI. to XXVIII. The conductivities in pure glycerol increase regularly, and are considerably higher than the corresponding values for lithium bromide. This is just what would be expected, if glycerol is a normal dissociating solvent. Cobalt chloride would dissociate into three ions, while lithium bromide would give only two, and the conductivities of the former salt would accordingly be greater.

The results are plotted as curves in Figures IV., V., and VI. The curves are in every respect analogous to those for lithium bromide, except in one minor point, to be seen in Figure V. Here the values of conductivity of cobalt chloride in pure ethyl alcohol are abnormally low (at least for all except the most dilute solutions), considering it is a ternary electrolyte. Lithium bromide, for instance, in the tenth-normal solution in ethyl alcohol, has a molecular conductivity of 15.8 at 25° , and we should expect, other things being equal, that cobalt chloride would give a value about 50 per cent greater than

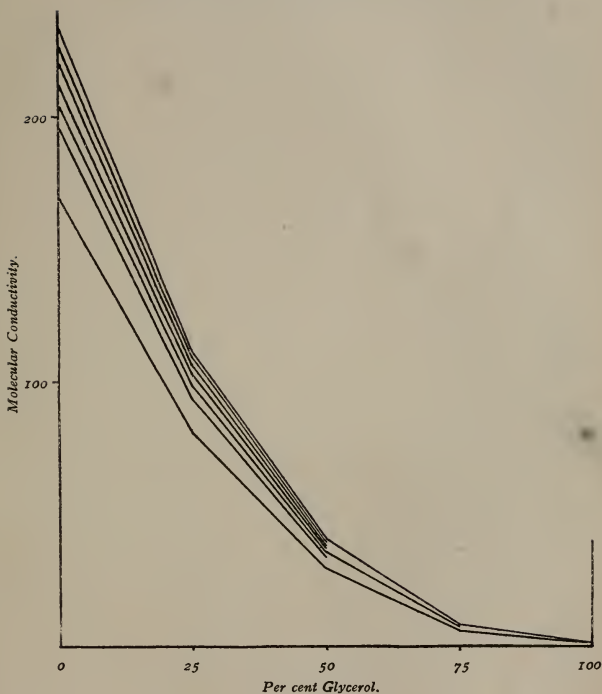


Fig. IV.—Conductivity of Cobalt Chloride in Glycerol-Water at 25°.

this. The value of μ_{v25° for cobalt chloride in ethyl alcohol is, however, only 4.71. But knowing that many of the halides of the heavy metals tend to form complexes when dissolved in organic solvents, it was suspected that these low results, at least in the concentrated solutions, were due to partial polymerization of the cobalt chloride molecules. This point was kindly tested for us by Mr. H. R. Kreider. He showed by the boiling point method that the dissociation of cobalt chloride in ethyl alcohol, for concentrations ranging near



Fig. V.—Conductivity of Cobalt Chloride in Glycerol-Ethyl Alcohol at 25°.

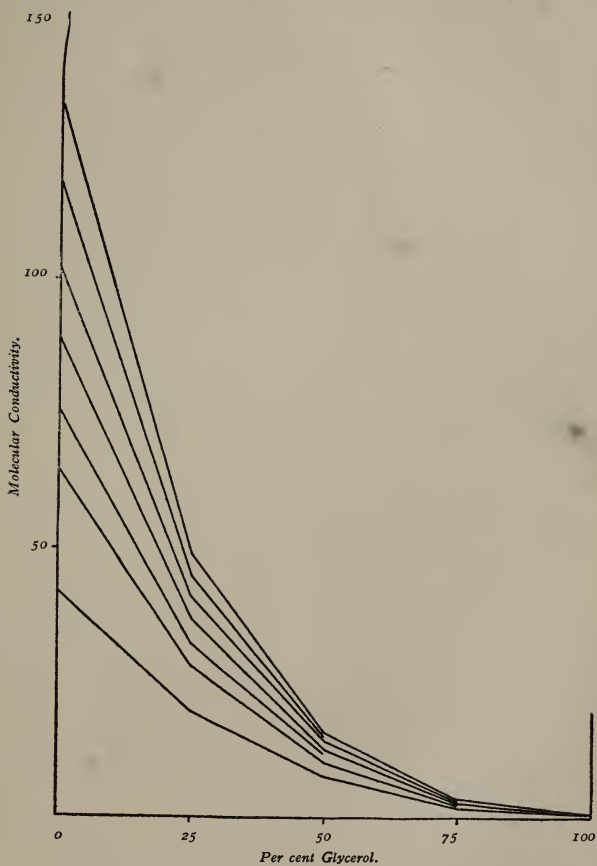


Fig. VI.—Conductivity of Cobalt Chloride in Glycerol-Methyl Alcohol at 25°.

tenth-normal, is apparently negative; or, in other words, the indicated molecular weight is greater than that calculated for CoCl_2 . Some of his results are given here.

M. W. = 129.96.	
Volume.	M. W. found.
8.1	155
13.0	134
13.3	131

The association appears in all three solutions, and since most other salts are dissociated 20 to 30 per cent in ethyl alcohol at these concentrations, we may consider the low conductivity of cobalt chloride in this case to be due to this cause. The same thing is shown in methyl alcohol solutions. The value of μ_{v25}° for lithium bromide in tenth-normal solution is 50.0, against a corresponding value of 41.9 for cobalt chloride. The difference is not so striking here, probably because methyl alcohol is a stronger dissociant than ethyl alcohol.

Potassium Iodide.

Kahlbaum's pure potassium iodide was recrystallized, and dried to constant weight at 150° . It showed no appreciable impurity.

Tables XXIX. to XLI. give the conductivities of potassium iodide in glycerol, and in the mixed solvents. Again, the conductivities increase nearly regularly with dilution, and are a little higher than those of lithium bromide, and about 50 per cent less than the conductivities of cobalt chloride, as we should expect. The results in the mixtures are represented in Figures VII., VIII., and IX., and are in every respect like those obtained for the other two salts. The conductivities are less than the averages in each case.

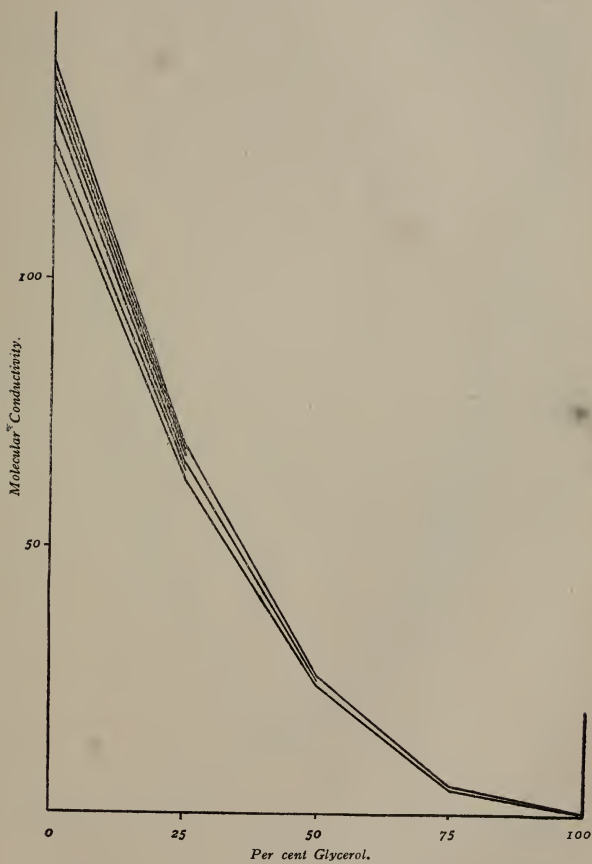


Fig. VII.—Conductivity of Potassium Iodide in Glycerol-Water at 25°.

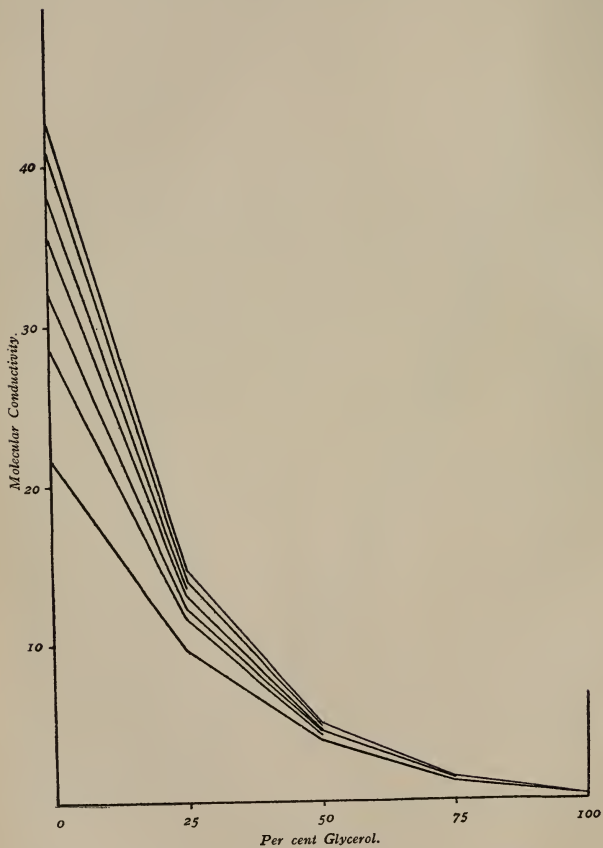


Fig. VIII.—Conductivity of Potassium Iodide in Glycerol-Ethyl Alcohol at 25°.

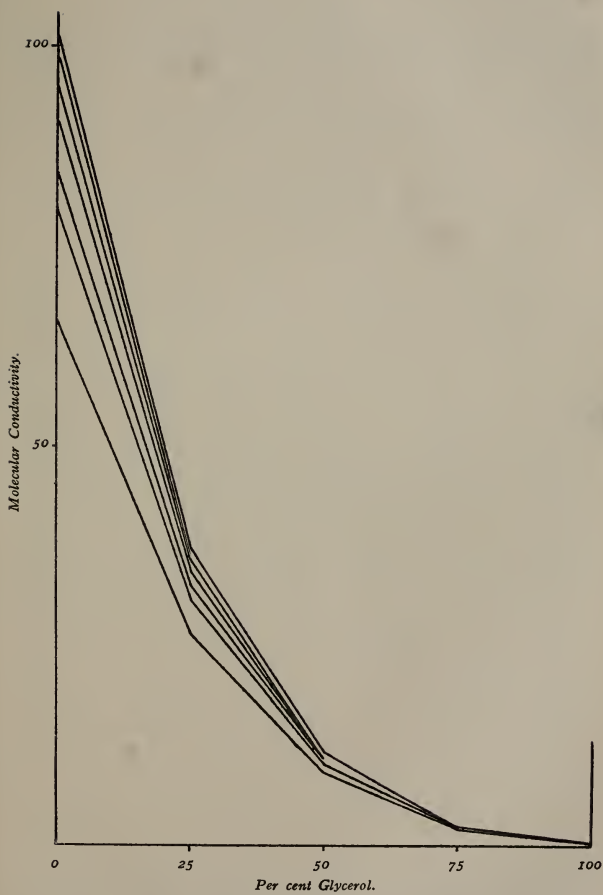


Fig. IX.—Conductivity of Potassium Iodide in Glycerol-Methyl Alcohol at 25°.

Temperature Coefficients of Conductivity.

The most interesting features in this connection are the *very large temperature coefficients of conductivity of the solutions in pure glycerol*. In tenth-normal solution, these are for lithium bromide, cobalt chloride, and potassium iodide, respectively, 10.6 per cent, 10.23 per cent and 10.87 per cent between 25° and 35° , and 8.71 per cent, 8.36 per cent, and 8.44 per cent between 35° and 45° . *These are much the largest temperature coefficients of conductivity thus far observed between these temperatures, and they are closely related to the temperature coefficients of fluidity.*

In the solutions of cobalt chloride in ethyl alcohol, *negative temperature coefficients* of conductivity occur. These have also been noticed by Jones and McMaster in certain solutions of the same salt in mixtures of acetone and the alcohols. In the present case, the temperature coefficient of the tenth-normal solution is positive, though very small, and in the fiftieth-normal solution it becomes negative. The temperature coefficients reach a minimum in the hundredth-normal solution, and then increase regularly, again becoming positive in the dilute solutions. Temperature coefficients of conductivity in ethyl alcohol are always small, and it is known that the degree of ionization decreases with rising temperature. We have already proved that cobalt chloride in ethyl alcohol has a strong tendency to polymerize. The occurrence of negative temperature coefficients of conductivity, therefore, shows that the decrease in ionization, due to rise in temperature, is more than sufficient to overcome the effect of increased ion velocity, brought about by increased fluidity.

In the mixed solvents, the temperature coefficients of conductivity in no case follow the law of averages, but, like the conductivities, are always less than the calculated values.

We have thus shown that for solutions in mixtures of glycerol with water or the alcohols, the molecular conductivities are always less than the averages calculated from the conductivities in the component solvents. Hence, we may conclude that glycerol is a solvent which, when mixed with another,

gives a mixture whose properties are not additive, and in this respect glycerol resembles water. In the three cases tested, glycerol causes some change in the state of molecular aggregation of the other solvents, producing mixtures similar, in many ways, to mixtures of water with the alcohols or acetone. We can now proceed to show that the departure from the law of averages is just as pronounced when we examine the fluidities of the mixtures of glycerol.

Table XLII.—Viscosity and Fluidity of Solutions in Mixtures of Glycerol and Water at 25° and 35°.

Water.					
Solution.	η 25.	η 35.	ϕ 25.	ϕ 35.	T. C. ϕ .
LiBr	0.009011	0.00723	110.99	138.33	0.0246
CoCl ₂	0.009209	0.00745	108.58	134.26	0.0237
KI	0.008847	0.007191	113.02	139.06	0.0231
Solvent	0.00891	0.00720	112.25	138.89	0.0237

25 Per Cent Glycerol and Water.

LiBr	0.02064	0.01552	48.45	64.44	0.0330
CoCl ₂	0.02156	0.01624	46.49	61.65	0.0326
KI	0.01991	0.01509	50.23	66.25	0.0319
Solvent	0.02003	0.01518	49.91	65.86	0.0319

50 Per cent Glycerol and Water.

LiBr	0.06246	0.04346	16.01	23.01	0.0437
CoCl ₂	0.06659	0.04632	15.02	21.59	0.0438
KI	0.06060	0.04252	16.50	23.52	0.0425
Solvent	0.06145	0.04272	16.27	23.41	0.0438

75 Per cent Glycerol and Water.

LiBr	0.3330	0.2020	3.003	4.949	0.0647
CoCl ₂	0.3645	0.2202	2.743	4.541	0.0656
KI	0.3246	0.1982	3.081	5.046	0.0638
Solvent	0.3203	0.1954	3.122	5.118	0.0639

Table XLIII.—Viscosity and Fluidity of Solutions in Mixtures of Glycerol and Ethyl Alcohol at 25° and 35°.

Ethyl Alcohol.					
Solution.	η 25.	η 35.	ϕ 25.	ϕ 35.	T. C. ϕ .
LiBr	0.01235	0.009864	80.92	101.37	0.0253
CoCl ₂	0.01193	0.009828	83.80	101.75	0.0214
KI	0.01177	0.00960	84.95	104.16	0.0226
Solvent	0.01110	0.009068	90.07	110.28	0.0224

25 Per cent Glycerol and Ethyl Alcohol.

LiBr	0.04574	0.03305	21.86	30.26	0.0384
CoCl ₂	0.04919	0.03612	20.33	27.69	0.0362
KI	0.0452	0.03290	22.12	30.39	0.0374
Solvent	0.04367	0.03188	22.90	31.37	0.0370

50 Per cent Glycerol and Ethyl Alcohol.

LiBr	0.2275	0.1413	4.515	7.075	0.0588
CoCl ₂	0.2449	0.1569	4.084	6.375	0.0561
KI	0.2059	0.1327	4.856	7.537	0.0552
Solvent	0.2053	0.1323	4.871	7.559	0.0552

75 Per cent Glycerol and Ethyl Alcohol.

LiBr	1.193	0.6455	0.8382	1.549	0.0848
CoCl ₂	1.353	0.7381	0.7391	1.355	0.0833
KI	1.1005	0.6038	0.9089	1.656	0.0822
Solvent	1.0842	0.5971	0.9223	1.675	0.0816

Table XLIV.—Viscosity and Fluidity of Solutions in Mixtures of Glycerol and Methyl Alcohol at 25° and 35°.

Methyl Alcohol.

Solution.	η 25.	η 35.	ϕ 25.	ϕ 35.	T. C. ϕ .
LiBr	0.006097	0.005305	164.01	188.52	0.0149
CoCl ₂	0.006365	0.005404	157.10	181.65	0.0135
KI	0.005942	0.005149	168.31	194.21	0.0154
Solvent	0.005654	0.004918	176.86	204.59	0.0149

25 Per cent Glycerol and Methyl Alcohol.

LiBr	0.02105	0.01647	47.51	60.72	0.0279
CoCl ₂	0.02247	0.01735	44.51	57.64	0.0295
KI	0.02019	0.01588	49.52	62.98	0.0272
Solvent	0.01962	0.01539	50.97	64.97	0.0274

50 Per cent Glycerol and Methyl Alcohol.

LiBr	0.1012	0.06945	9.882	14.40	0.0458
CoCl ₂	0.1080	0.07451	9.258	13.42	0.0450
KI	0.0936	0.06353	10.68	15.54	0.0474
Solvent	0.0928	0.06379	10.78	15.68	0.0454

75 Per cent Glycerol and Methyl Alcohol.

LiBr	0.6525	0.3803	1.532	2.630	0.0717
CoCl ₂	0.7379	0.4165	1.352	2.401	0.0776
KI	0.6288	0.3637	1.590	2.750	0.0729
Solvent	0.6073	0.3552	1.647	2.815	0.0709

Table XLV.—Viscosity and Fluidity of Solutions in Glycerol at 25° and 35°.

Solution.	η 25.	η 35.	ϕ 25.	ϕ 35.	T. C. ϕ .
LiBr	6.786	3.192	0.1474	0.3133	0.1126
CoCl ₂	7.530	3.364	0.1328	0.2973	0.1261
KI	6.723	3.139	0.1487	0.3186	0.1143
Solvent	6.330	2.9403	0.1580	0.3401	0.1153

Viscosity and Fluidity.

Tables XLII. to XLV., inclusive, give the viscosities and fluidities of the pure solvents, the mixed solvents, and the tenth-normal solutions of the three salts in these liquids. The fluidities of the solutions are, as usual, in nearly every case less than those of the corresponding solvents. In three solutions, however, we have the phenomenon of negative viscosity. These are potassium iodide in water, and in 25 and 50 per cent glycerol and water, at both 25° and 35°. An explanation of negative viscosity has been given by Jones and Veazey.¹ It is interesting to find that the fluidity of even so immobile a liquid as 50 per cent glycerol and water is increased by the addition of potassium iodide. In the 75 per cent mixture, the viscosity coefficient is again positive, but the difference between the viscosity of the mixture and of tenth-normal potassium iodide in it is not great. The salt does not lower the viscosity of pure glycerol, nor of any of the other solvents used.

But if we examine the viscosities of the solutions in pure glycerol, we see that the effect of the several salts on the viscosity of the solvent is in inverse ratio to the molecular volumes of the salts. Potassium iodide, with the largest molecular volume, increases the viscosity of glycerol less than does lithium bromide, which has a slightly smaller molecular volume. The latter salt, in turn, increases the viscosity of glycerol much less than does cobalt chloride, which has much the smallest molecular volume of the three. *Relations exactly analogous to these* have been pointed out by Jones and Veazey, and the mechanism of the effect has been sufficiently discussed in the first part of this work.

¹ THIS JOURNAL, 37, 405 (1907).

The viscosity of pure glycerol at 25° —6.330—is 1120 times that of methyl alcohol at the same temperature. A wide range of viscosity has thus been covered, yet the same relations hold as obtain in mixtures of the much more fluid solvents studied by Jones and his coworkers. The fluidities at 25° are plotted as curves in Fig. X. Curve I. represents the fluidities of glycerol-methyl alcohol mixtures, curve II. represents glycerol-water, and curve III. represents glycerol-ethyl alcohol. The curves resemble the conductivity curves very closely, show the same sagging, and have no minima.

The temperature coefficient of fluidity of pure glycerol between 25° and 35° is 11.53 per cent, and this is very nearly equal to the temperature coefficients of conductivity of the salts used in this work. In all the solutions, the temperature coefficient of fluidity is greater than the temperature coefficients of conductivity, as has been observed in practically all cases heretofore. This is probably due partly to the decrease of dissociation with rising temperature.

It will be seen that in the majority of cases, the temperature coefficient of fluidity of any solution is slightly greater than that of the solvent. As is known, dissociation decreases slightly with rising temperature. This would cause the solution at higher temperature to contain a greater number of whole molecules, whose volume would be equal to that of their component ions, but whose frictional surfaces would be less. This would decrease the total frictional surface of the particles in the solution, and an increase in the fluidity would result, in addition to that caused by the ordinary increase in the fluidity of the pure solvent. This relation does not hold for all of the temperature coefficients of fluidity, but the exceptions are not many, and it would seem that an explanation like the above is at least partially correct.

A comparison of the conductivity and fluidity curves shows, then, that the two phenomena, in mixtures of glycerol with water or the alcohols, are very closely parallel. No minima are found, but every curve shows a falling below the straight line of averages. Hence, we must conclude that glycerol is a solvent resembling water more closely than it does the

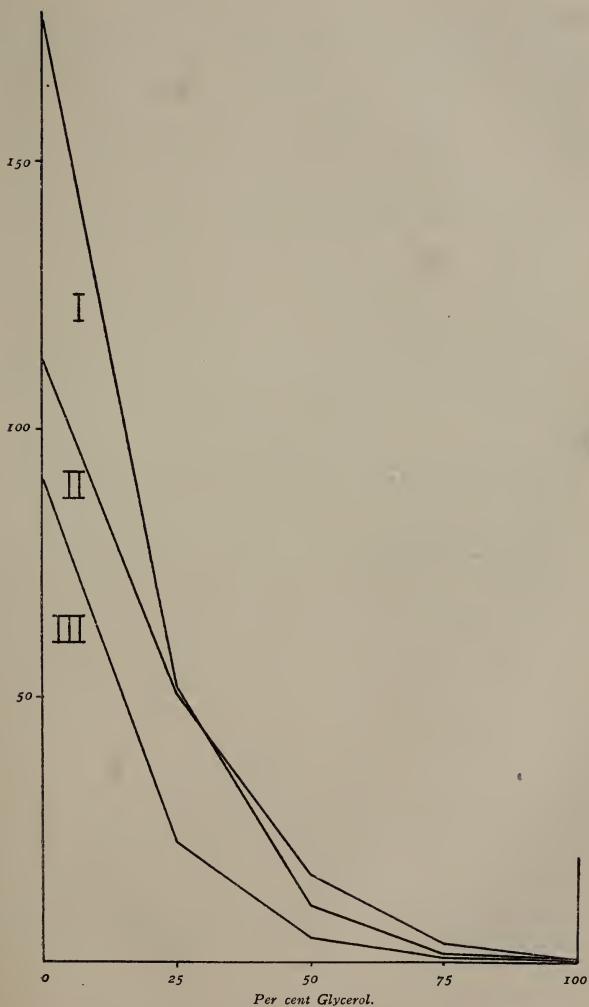


Fig. X.—Fluidities of Glycerol Mixtures at 25°.

alcohols, in that mixtures containing it do not have additive properties. This resemblance to water comes out more strikingly when we examine the relative values of the conductivities of the three salts studied here, in the different pure solvents. In water, cobalt chloride, being a ternary electrolyte, has a greater conductivity than potassium iodide, and potassium iodide again has a conductivity greater than lithium bromide. The same order is found in glycerol. In ethyl alcohol, and in the tenth-normal solutions in methyl alcohol, the order is potassium iodide, lithium bromide, cobalt chloride. We have already shown that cobalt chloride in ethyl alcohol forms complexes. It is evident that in glycerol the same salt does not form complexes, but behaves like a normal ternary electrolyte in a strongly dissociating solvent. It seems to be broken down, at least partly, into three ions, even in the fairly concentrated solutions in glycerol, and in this point the latter resembles water rather than the alcohols.

The conductivities of the several electrolytes in pure glycerol do not reach limiting values in the dilutions worked with here, but the conductivities for dilutions of four-hundredth-normal and more are increasing very slowly; in other words, complete dissociation is probably reached in glycerol solutions at a comparatively small volume. This feature again recalls the dissociating action of water.

If we multiply 0.35, the highest conductivity obtained for potassium iodide in glycerol at 25°, by 6.330, the viscosity of the solvent at that temperature, the product is 2.22. Similarly, at 35° the product is 2.10. These numbers, nearly identical, represent lower limits, so to speak of the product $\mu_{\infty} \eta$ for glycerol. It will be recalled that Walden found this value to be nearly a constant, independent of temperature, for about thirty organic solvents. Water and glycol, with values equal to 1.0 and 1.32 respectively, were exceptions. Glycerol thus becomes another exception, with a product of at least 2.10. If we compare methyl alcohol, the simplest monacid carbinol, with glycerol, the simplest diacid carbinol, and with glycerol, the simplest triacid carbinol, we see that

conductivity does not increase proportionately to fluidity, but to some fractional power of fluidity.

Solvent.	$\mu_{\infty} \eta$.
CH_3OH	0.72
$\text{C}_2\text{H}_4(\text{OH})_2$	1.32
$\text{C}_3\text{H}_5(\text{OH})_3$	2.10

A similar conclusion has been drawn by Green¹ from a study of the conductivity and viscosity of solutions of lithium chloride in water containing various amounts of sucrose, and he finds that $\mu_{\infty} = K \phi^{0.7}$.

Summary of Facts Established.

(1) Glycerol, with water, or with methyl or ethyl alcohol, forms binary mixtures whose properties are not additive.

(2) The conductivity curves of three electrolytes in these mixtures in no case obey the law of averages.

(3) The same is true of the fluidity curves.

(4) The temperature coefficients of conductivity of solutions in pure glycerol are very large, and nearly identical with the temperature coefficients of fluidity.

(5) Glycerol, as a dissociating liquid, resembles water more closely than it does the alcohols.

(6) Conductivity increases with fluidity, but instead of increasing at the same rate, varies as some fractional power of fluidity.

PHYSICAL CHEMICAL LABORATORY,
JOHNS HOPKINS UNIV.,
Baltimore, May, 1909.

REVIEWS.

DIE LAGERUNG DER ATOME IM RAUME. Von J. H. VAN'T HOFF. Dritte umgearbeitete und vermehrte Auflage, mit 24 eingedruckten Abbildungen. Braunschweig: Druck und Verlag von Friedrich Vieweg und Sohn. pp. 147. 1908. Price, M. 4.50.

This work by van't Hoff is one of his three or four epoch-making contributions to chemistry. Indeed, it may be fairly said that the contributions of van't Hoff to the general sub-

¹ J. Chem. Soc., 93, 2049 (1908).

ject of stereochemistry, or the positions of the atoms in space in organic compounds, have furnished the philosophy for organic chemistry for the last quarter of a century.

The preface to the first edition of this little book was written in 1876 by Johannes Wislicenus, then in Würzburg.

The preface to the second edition was written in 1894, by the same chemist who was then in Leipzig, and from whose laboratory so much of importance was contributed to this subject.

This splendid man is now gone, and van't Hoff writes his own brief preface to the third edition in 1908.

Although the work is so well known to mature chemists, it may not be as familiar to the younger men. A brief reference to its contents may, therefore, not be out of place. The first nine chapters are devoted to the stereochemistry of carbon: The asymmetric carbon atom; Compounds with several asymmetric carbon atoms; Ring union; Preparation of isolated antipodes; Determination of position in stereoisomers; Transformation of optical antipodes; Double and triple union in carbon compounds; and The numerical value of the rotatory power.

The second part of the book is devoted to the stereochemistry of elements other than carbon, including sulphur, selenium, tin, silicon, and optical isomerism in the case of pentavalent nitrogen.

The new edition brings the subject up-to-date, and like any contribution from the pen of van't Hoff, will be most heartily welcomed to the chemical world. No chemist can afford to be without a copy of the newest edition of this book.

H. C. J.

THE ELEMENTS OF PHYSICAL CHEMISTRY. By J. LIVINGSTON R. MORGAN, PH.D., Professor of Physical Chemistry in Columbia University. Fourth edition, revised and enlarged. New York: John Wiley and Sons; London: Chapman and Hall, Limited. 1908. pp. xiv + 539. Price, \$3.

To those familiar with the previous editions¹ of this interesting book, the scope of this new edition is indicated by the words of the author: "All the changes made in this edition have been undertaken with the view of bringing the subject matter up to date and making the various relations more intelligible to the average nonmathematical reader The sections on 'indicators' and 'general analytical reactions' have been omitted, for they are now presented in all the better text-books on analytical chemistry."

It is surprising how much is told in this little volume. There

¹ See THIS JOURNAL, 21, 459; 28, 242; 34, 593.

is scarcely a paragraph that is not packed with information and the range of topics discussed is remarkably wide. Too often the chemist finds physico-chemical methods as presented unintelligible and therefore useless. In this book, however, we find remarkably clear presentation and numerous examples of the practical application of the methods described. A great many calculations are explained throughout the text and a large number of problems is subjoined.

The writer follows Ostwald in dispensing with the atomic and molecular hypotheses. This seems of doubtful advisability in a text-book of "elements" in view of the fact that the objections to these hypotheses are purely philosophical. It certainly does not aid the comprehension of the average student to dispense with such excellent tools unless some better ones are offered.

The use of the term "chemical energy" (p. 426 ff.) is rather ambiguous from a thermodynamic standpoint, meaning, as the author does, change in total energy and not free or reaction energy. On p. 442 the electromotive force of a calomel electrode is misprinted as -0.0613 instead of -0.613 .

Any objections, however, are of minor importance, and this new edition will prove a valuable book for students of the subject.

JOEL H. HILDEBRAND.

QUALITATIVE ANALYSE VOM STANDPUNKTE DER IONENLEHRE. VON DR. WILHELM BÖTTGER, Privatdozent und Oberassistent am Phys.-chem. Institut der Universität Leipzig. Zweite, umgearbeitete und stark erweiterte Auflage. Mit 24 Figuren im Text, einer Spektraltafel und besonderen Tabellen zum Gebrauche im Laboratorium. Leipzig: Verlag von Wilhelm Engelmann. 1908. pp. 524.

The first edition of this admirable book by Dr. Böttger is very well known. A large amount of work has been expended in revising it, and to good purpose. The author tells us that a year of strenuous toil has been devoted to the preparation of the second edition.

This work deals with the subject of qualitative analysis, not in the empirical manner in which it was taught a comparatively few years ago, but from the standpoint of the epoch-making generalizations of the newer physical chemistry. Under "Fundamental Principles," the ionic theory, valence, reversible reactions, the law of mass action, hydrolysis, amphoteric electrolytes, oxidation and reduction, colloids, catalyzers, etc., are considered; and it will be recognized that these principles lie right at the basis of chemical science.

A large section of the book discusses the characteristic

reactions of the cations or metals, and still another the characteristic reactions of the anions or acid radicals.

The usual tests for cations and anions in terms of the several groups, together with preliminary tests, are considered at length.

The book contains a fairly large section devoted to the rare earths which is of unusual interest and importance. The so-called rare earths are many of them no longer rare, and all of them have acquired a special interest in the last few years, due especially to the work of the Welsbach Light Co., which has separated many of these substances in large quantities. The methods for separating these substances are discussed at length.

All in all, this is easily our most modern and scientific treatise on the subject of qualitative analysis.

H. C. J.

GENERAL CHEMISTRY FOR COLLEGES. By ALEXANDER SMITH, Professor of Chemistry and Director of General and Physical Chemistry in the University of Chicago. New York: The Century Co. 1908. pp. 529.

Professor Smith's "General Inorganic Chemistry" is marked by an excellent arrangement of theory and fact, with more physical-chemical theory than is found in any other text-book of inorganic chemistry, and also by proper sequence and great clearness.

The "General Chemistry for Colleges" is written on the same plan. It contains less theory than the large book, but what is given is developed very fully; it is much simpler and better fitted for college students. Although much of the matter of the larger book is retained in this, there is so much that is quite new in treatment, that it can not be regarded as an abridgement of the larger work.

This book deserves the success with beginners that the larger book has with older students.

E. R.

A TEXT-BOOK OF BOTANY AND PHARMACOGNOSY. By HENRY KRAEMER, PH.B., PH.D., Professor of Botany and Pharmacognosy, and Director of the Microscopical Laboratory, in the Philadelphia College of Pharmacy. Third edition, revised and enlarged. Illustrated with over 300 plates comprising about 2000 figures. J. B. Lippincott Co. Philadelphia. pp. 850.

As is indicated in the sub-title this book is intended for students of pharmacy, as a reference book for pharmacists, and as a hand-book for food and drug analysts. Since the first edition in 1902, this book has more than doubled in size and corresponding usefulness and now contains 850 pages.

¹ THIS JOURNAL, 36, 217.

The subject matter is divided into three parts: I. Botany. II. Pharmacognosy. III. Reagents and Microscopical Technique. The first part occupies about one-half the book and in it the main facts on classification, morphology, and histology are given in a manner which should make it interesting and instructive to pharmacy students.

In the second part the principal official and nonofficial drugs are described. Many cuts accompany the descriptions, illustrating the drug structure. The chapter on powdered drugs is also well illustrated, many of the cuts being original, others taken from such well-known sources as Meyer, Moeller and Vogl. A key for the identification of vegetable powders is given, which makes this part especially valuable to pharmacists who use the microscope.

The press work on the book is excellent and it should prove a valuable addition to the library of the food and drug analyst and pharmaceutical student.

PRINCIPLES AND PRACTICE OF AGRICULTURAL ANALYSIS. Vol. II. By HARVEY W. WILEY, A.M., PH.D., Chief of the Bureau of Chemistry, U. S. Department of Agriculture, Washington, D. C. Second edition, revised and enlarged. The Chemical Publishing Co., Easton, Pa. pp. 680.

This volume is more than twice the size of the corresponding volume of the first edition.

Much of the material relating to ammonia, nitrous and nitric acid, which appeared in the first volume of the first edition, has been rewritten and transferred to this volume.

This work is unlike that frequently seen in "second editions" for the reason that the volume has been most carefully and conscientiously rewritten, enlarged, and brought up to date.

The new features are: a description of the processes employed in combining atmospheric nitrogen in the manufacture of calcium cyanamide and calcium nitrate; a résumé of the experiments thus far made for the purpose of determining their agricultural value; and the introduction of methods for the examination and analysis of fungicides and insecticides.

Part first opens with a general discussion, followed by a description of methods for sampling all classes of materials preparatory to analysis. This part is devoted primarily to a discussion of phosphates in all of their relations, such as occurrence, origin, associated ingredients, agricultural utilization, and chemical analysis.

Part second is devoted to natural and artificial nitrogenous compounds and the analytical methods employed in their analysis in many of the leading countries of the world.

Part third is devoted to a review of the origin, extent, and

utilization of the great deposits of potassium salts in Germany, to a discussion of other sources of potash, and to the various analytical methods for its determination.

Part fourth embraces a discussion of miscellaneous fertilizers; also of insecticides, fungicides, and methods for their analysis.

In considering methods of analysis not only those now in use but most of the earlier methods of prominence are discussed. Frequent mention is made of the advantages or disadvantages which certain methods afford. In view of this feature and on account of the general fund of information relating to the origin, methods of manufacture, and utilization of many of the materials which are discussed, the work is made indispensable not only to the ordinary analyst, but also to agricultural and manufacturing chemists and students of agriculture.

One might take exception to the high tribute paid to natural iron and aluminum phosphates as fertilizers; possibly also undue prominence is given to the discussion of the manurial value of finely pulverized feldspar, and such reference as "no claim has been made that ground feldspar is an efficient substitute, under all circumstances, for potash salts," seems likely to lead to undue expectations as to its efficiency.

Apparently few errors, oversights, or important omissions have occurred, which is perhaps exceptional for so large a volume, prepared by a single author.

But few other recent writers have had the good fortune to render the chemists of the United States and of the entire world so largely their debtors.

H. J. WHEELER.

AMERICAN CHEMICAL JOURNAL

[Contributions from the Sheffield Laboratory of Yale University.]

CLXVIII.—RESEARCHES ON PYRIMIDINES: THE PREPARATION OF 1,4-DIMETHYLURACIL AND OF THE MONOBENZYL DERIVATIVES OF 4-METHYLURACIL.¹

[FORTY-FOURTH PAPER.]

BY HENRY L. WHEELER AND DAVID F. MCFARLAND.

Behrend² has shown, in his work on the methylation of 4-methyluracil with alkali and methyl iodide, that the three products 1,4-dimethyluracil, 3,4-dimethyluracil, and 1,3,4-trimethyluracil, are all formed and have to be dealt with in addition to unaltered material.

List³ found that 2-thio-4-methyluracil (I.) is readily methylated and that the alkyl group unites with the sulphur, producing 2-methylmercapto-4-methyl-6-oxypyrimidine (II.). List did not determine what was formed on further alkylation.

¹ Part of a Thesis presented by David F. McFarland for the Degree of Ph.D., Yale, 1909.

² Behrend and Dietrich: *Ann. Chem. (Liebig)*, **309**, 265 (1899). Behrend and Meyer: *Ber. d. chem. Ges.*, **33**, 624 (1900). Behrend and Thurn: *Ann. Chem. (Liebig)*, **323**, 160 (1902).

³ *Ann. Chem. (Liebig)*, **236**, 12 (1886).

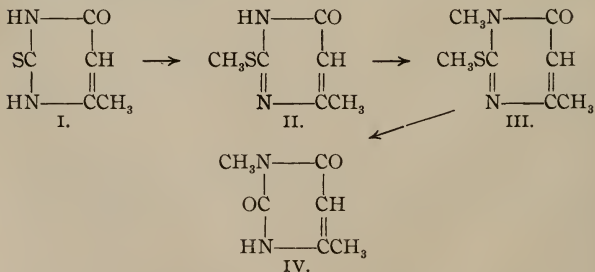
In previous papers from this laboratory it has been shown that 2-mercapto-6-oxypyrimidines usually give a mixture of the 1- and 3-alkyl derivatives on further alkylation.¹

We will now show that the potassium salt of List's 2-methylmercapto-4-methyl-6-oxypyrimidine, in alcoholic solution, alkylates almost entirely in the 1-position with methyl iodide and that 1,4-dimethyl-2-methylmercapto-6-oxypyrimidine (III.) is formed. There are indications also, in this reaction, of the formation of 2-methylmercapto-4-methyl-6-methoxypyrimidine in small amount.

Since the alkylmercaptopyrimidines easily evolve mercaptan and form the corresponding uracil derivatives on boiling with hydrochloric acid, this method is the best (*Darstellung*) for the preparation of 1,4-dimethyluracil (IV.).

By condensing acetoacetic ethyl ester with thiourea in alcoholic solution and in the presence of two molecular proportions of sodium ethylate, a quantitative yield of List's 2-thio-4-methyluracil (I.) may be obtained. The condensation also takes place in alkaline aqueous solution but the yield is not as good. Even this process is far superior to the original methods.²

The steps in the synthesis of 1,4-dimethyluracil may be represented as follows:



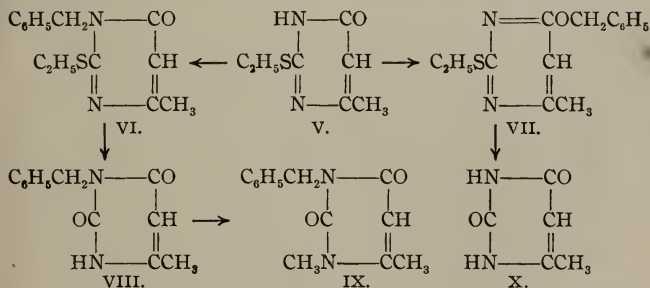
Acetoacetic ethyl ester condenses with ethylpseudothiourea,

¹ For a list of these cases see our forty-third paper on pyrimidines, *THIS JOURNAL*, **42**, (1909).

² Nencki and Sieber: *J. prakt. Chem.*, [2] **25**, 72 (1882). List: *Loc. cit.*

$\text{H}_2\text{N} - \text{C}(\text{SC}_2\text{H}_5)\text{NH}$, in alkaline aqueous solution more smoothly and gives a larger yield (over 80 per cent) of mercaptopyrimidine than in the case of the corresponding condensations of the sodium salts of either ethyl formylacetate or ethyl formylpropionate.

When 2-ethylmercapto-4-methyl-6-oxypyrimidine (V.), prepared in this manner, was treated with sodium hydroxide and benzyl chloride, a mixture of 1-benzyl-2-ethylmercapto-4-methyl-6-oxypyrimidine (VI.) and 2-ethylmercapto-4-methyl-6-benzyloxyypyrimidine (VII.) was obtained. This mixture, which was obtained as an oil insoluble in alkali, could not be separated by distillation under reduced pressure. When it was boiled with hydrochloric acid mercaptan escaped and a new benzyl-4-methyluracil, melting at 194° , along with 4-methyluracil, was obtained.



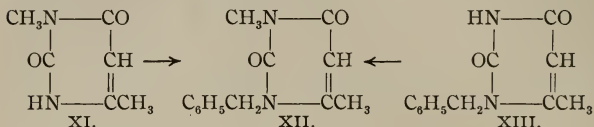
Hagen¹ described a benzyl-4-methyluracil melting at 233° which he obtained in very small amount—the quantity being only sufficient for analysis—by heating the dry potassium salt of 4-methyluracil at a high temperature with benzyl chloride. This substance is given in Beilstein's *Handbuch*² as 1-benzyl-4-methyluracil (VIII.).

We now find that this is incorrect and that the compound is 3-benzyl-4-methyluracil (XIII.). The proof of the structure of these compounds was obtained as follows: 1,4-Dimethyl-

¹ Ann. Chem. (Liebig), **244**, 9 (1888).

² [3] **2**, 529.

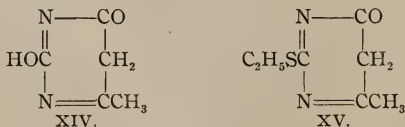
uracil (XI.) was treated with potassium hydroxide and benzyl chloride in alcoholic solution. This gave 1,4-dimethyl-3-benzyluracil (XII.), melting at 85°–86°. Hagen's benzylmethyluracil, which we find is easily obtained, along with the isomer melting at 194°, when 4-methyluracil, potassium hydroxide and benzyl chloride are warmed in alcoholic solution, was then methylated; the same dimethylbenzyluracil melting at 85°–86° was thereby obtained.



When the new 1-benzyl-4-methyluracil (VIII.) was methylated it gave the isomeric 1-benzyl-3,4-dimethyluracil (IX.), melting at 164°.

The possibility of an alkylation taking place in the 5-position in the case of pyrimidines derived from acetoacetic ester had to be considered, at this point, before the above results could be taken as proof of the structures assigned to the benzyl compounds in question. Barbituric acid or 2,4,6-trioxy-pyrimidine alkylates under the same conditions in the 5-position.¹

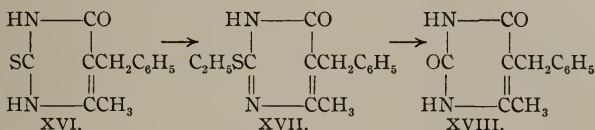
From the analogy which exists between acetoacetic ester and malonic ester it might be expected that 4-methyluracil or 2-ethylmercapto-4-methyl-6-oxypyrimidine might react in the tautomeric forms represented by formulas (XIV.) and (XV.) and yield 5-benzyl derivatives.



In order to prepare 4-methyl-5-benzyluracil (XVIII.) it was necessary to condense benzylacetoacetic ester with a urea

¹ Conrad and Gutzeit: *Ber. d. chem. Ges.*, **14**, 1643 (1881); **15**, 2846 (1882). Fischer and Dilthey: *Ann. Chem. (Liebig)*, **333**, 338 (1904).

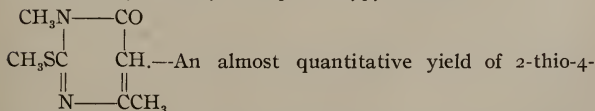
derivative. This ester proved to be one of those β -ketone esters which failed to condense satisfactorily by the general method with the pseudothiureas in aqueous solution. We find, however, that it condenses in alcoholic solution with thiourea in the presence of sodium ethylate, giving the sodium salt of 2-thio-4-methyl-5-benzyluracil (XVI.). In order to desulphurize this it was found best to convert it into 2-ethyl mercapto-4-methyl-5-benzyl-6-oxypyrimidine (XVII.) which, on boiling with hydrochloric acid, easily gave the desired 4-methyl-5-benzyluracil (XVIII.) melting at 249° - 250° .



Since this compound, melting at 249° - 250° , is different from either of the above benzylmethyluracils it follows that in the alkylation of the pyrimidines derived from acetoacetic ester, under the conditions stated, the benzyl group does not enter the 5-position, and that the various benzyl compounds are correctly represented by the formulas given above. The isomeric benzyloxypyrimidines would not be stable when boiled with hydrochloric acid and are therefore excluded. This otherwise completes the list and settles the structure of the monobenzyl derivatives of 4-methyluracil.

EXPERIMENTAL PART.

1,4-Dimethyl-2-methylmercapto-6-oxypyrimidine,



methyluracil was usually obtained when 30 grams of acetoacetic ester and two molecular quantities of sodium ethylate, made by dissolving 10.6 grams of sodium in 200 cc. of absolute alcohol, were warmed for half an hour with 17.5 grams of thio-

urea. On evaporating the alcohol on the steam bath, which appears to render the condensation more nearly complete, the sodium salt of 2-thio-4-methyluracil remained. This salt easily dissolved in water. On addition of acetic acid to the solution, 2-thio-4-methyluracil was precipitated. The precipitate is apt to carry down with it some of the sodium salt, and it was found advisable to warm it, after filtering, with water acidified with acetic acid. Then on washing with water it is obtained pure and free from sodium.

When 2-thio-4-methyluracil is treated with two molecular proportions of potassium hydroxide and methyl iodide a considerable quantity of 2-methylmercapto-4-methyl-6-oxypyrimidine is obtained. In order to produce a satisfactory alkylation on the nitrogen it is necessary to use a greater excess of alkali and methyl iodide. Potassium hydroxide gives better results in nitrogen alkylation than sodium hydroxide.

Thirty grams of 2-thio-4-methyl-6-oxypyrimidine were dissolved with 35 grams of potassium hydroxide in 150 cc. of absolute alcohol. The potassium salt formed was much more soluble than the free pyrimidine. After cooling the solution, 94 grams of methyl iodide, an excess of 4 grams over that calculated for 3 molecular quantities, were gradually added and the mixture was allowed to stand two days. At the end of that time, about 6 hours' gentle heating on the steam bath was required to complete the reaction so that the solution gave no alkaline test with moist turmeric paper. The alcohol was then evaporated, under diminished pressure, and the solid residue was treated with dilute sodium hydroxide. The undissolved portion was filtered and washed with a little water. Twenty-five and one-tenth grams of 1,4-dimethyl-2-methylmercapto-6-oxypyrimidine melting at 85° – 90° were obtained. An additional 2.3 grams were recovered by shaking the alkaline mother liquor with ether, making the total yield of the compound 27.4 grams, or 76.4 per cent. of the calculated yield. From the alkaline solution 4.5 grams of 2-methylmercapto-4-methyl-6-oxypyrimidine, formed by incomplete methylation, were obtained on acidifying. Al-

lowing for this, the yield of 1,4-dimethyl-2-methylmercapto-6-oxypyrimidine becomes 91.2 per cent of the calculated.

In another experiment where only two molecular proportions of alkali and of methyl iodide were used with 27 grams of 2-thio-4-methyluracil, the amount of intermediate 2-methylmercapto-4-methyl-6-oxypyrimidine was largely increased, 8 grams of it being formed, with a corresponding decrease of dimethylmercapto compound. This shows that a large excess of alkali and of methyl iodide is necessary in order to completely methylate 2-thiouracil.

A small quantity of oily substance, with a pungent odor resembling that of parsnips, coated the material insoluble in alkali. It is probable that this oil is a 6-methoxy derivative but not enough was obtained to permit of its identification. When the material insoluble in alkali was crystallized from water it gave needles which melted sharply at 94° and the results on analysis agreed with those calculated for 1,4-dimethyl-2-methylmercapto-6-oxypyrimidine.

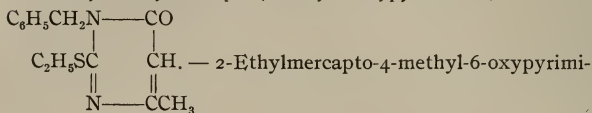
	Calculated for $C_7H_{10}ON_2S$.	Found.
N	16.22	16.47

The substance is readily soluble in alcohol and boiling water, crystallizing from aqueous solutions in silky needles. It is extremely soluble in ether, chloroform and benzene, and rather difficultly soluble in petroleum ether. It sublimes readily at the temperature of the steam bath, condensing again in fine silky needles. It is easily volatile with steam, and solutions containing it cannot be evaporated on the steam bath without loss.

Action of Hydrochloric Acid: 1,4-Dimethyluracil.—The above 1,4-dimethyl-2-methylmercaptopyrimidine was boiled for one hour with strong hydrochloric acid under a reflux condenser to prevent loss of the volatile compound. By this treatment it was quantitatively converted into Behrend's β -dimethyluracil (1,4-dimethyluracil). One recrystallization from hot water gave material melting sharply to a clear oil at 260° – 261° .

No trace of Behrend's isomeric α -dimethyluracil (3,4-dimethyluracil) melting at 220° was found in any of the mother liquors from the above. It is reasonably certain, therefore, that the corresponding 2-methylmercapto-3,4-dimethyl-6-oxy-pyrimidine was not formed in appreciable quantities.

1-Benzyl-2-ethylmercapto-4-methyl-6-oxy-pyrimidine,



dine was prepared by condensing acetoacetic ethyl ester with ethyl pseudothiurea in aqueous, alkaline solution; from 54.5 grams of acetoacetic ester a yield of 58.5 grams of crude mercapto compound was obtained, or 81.5 per cent of the calculated.

Twenty grams of this compound were added to a solution of 2.95 grams of sodium in 60 cc. of alcohol. After complete solution had been effected 16.2 grams of benzyl chloride were added and the mixture was heated on the water bath until no further alkaline reaction could be obtained with moist turmeric paper. This required about four hours. The alcohol was then evaporated under diminished pressure and the residue treated with 20 cc. of water and 10 cc. of dilute sodium hydroxide. A heavy oil remained undissolved. This was shaken out with ether; the ether solution was washed with water to remove alcohol, dried over solid potassium hydroxide, and filtered into a weighed flask. After evaporating the ether, 20.7 grams of oil remained, or 68 per cent of the calculated monobenzyl derivative. From the above alkaline solution 9 grams of unaltered substances and from the oil 6 grams of low-boiling material were obtained. Allowing for these weights, the yield of monobenzyl derivative is 87.5 per cent.

The oil was distilled at 22 mm. pressure and after about six grams of low-boiling oil (benzyl chloride?) had distilled over, the temperature rose to 224° and a little over 10 grams of material distilled between this and 236° . The greater part boiled near 227° . The temperature rose slowly, toward

the last to 260° , where the distillation was stopped. The fractions obtained were only slightly colored. None of them gave any solid even when cooled to -15° . Analyses were made of two separate fractions, one (A) boiling at 227° – 228° , and the other (B) at 228° – 260° . Both gave excellent results for a monobenzyl derivative of 2-ethylmercapto-4-methyl-6-oxy pyrimidine.

	Calculated for $C_{14}H_{16}ON_2S$.	A.	Found. B.
N	10.77	10.63	10.62

Action of Hydrochloric Acid: 1-Benzyl-4-methyluracil.—Two grams of the above fraction B were boiled for two hours with 15 cc. of concentrated hydrochloric acid, during which time mercaptan was evolved. The solution was evaporated to dryness, a solid residue weighing 1.3 grams, which nearly all dissolved in boiling water remaining. After filtering off the small amount of gummy residue which did not dissolve, a crystalline mass separated on cooling. It dissolved in boiling alcohol, and, on cooling gave colorless, rounded, lozenge-shaped crystals melting to a clear oil at 194° . Analysis showed this to be a monobenzyl-4-methyluracil.

	Calculated for $C_{12}H_{12}O_2N_2$.	Found.
N	12.96	12.93

The compound dissolves easily in cold chloroform, moderately in hot alcohol, and rather difficultly in hot water. The crystals from alcohol are characteristic.

By evaporation of the aqueous mother liquor from the above compound, material was obtained which crystallized in clusters of fine needles. It had no sharp melting point but decomposed at 270° – 300° . Analyses of this material gave results which agreed with those calculated for 4-methyluracil. When it was mixed with pure 4-methyluracil, the decomposition point was not lowered. From the two grams of oil hydrolyzed there were obtained about 0.3 gram of 1-benzyl-4-methyluracil and 0.6 gram of 4-methyluracil. This result indicates that the fraction of oil boiling at 228° – 260° consisted about

one-third of 1-benzyl-2-ethylmercapto-4-methyl-6-oxypyrimidine and two-thirds of the isomeric 2-ethylmercapto-4-methyl-6-benzylloxypyrimidine.

A similar hydrolysis of fraction A of the oil yielded approximately equal proportions of 4-methyluracil and 1-benzyl-4-methyluracil, so that this fraction consisted of a corresponding mixture of the mercaptobenzyl compounds. Repeated fractional crystallization of all the residues from this experiment failed to give any other substance besides the two described. No trace of the monobenzyl-4-methyluracil described by Hagen¹ was found, although a painstaking search was made for it.

Action of Benzyl Chloride upon 4-Methyluracil: 3-Benzyl-4-methyluracil.—The 4-methyluracil for this experiment was made by boiling 2-ethylmercapto-4-methyl-6-oxypyrimidine with strong hydrochloric acid until mercaptan ceased to be evolved. It was purified by crystallization from water.

Five and a half grams of 4-methyluracil were heated with 2.44 grams of potassium hydroxide in 50 cc. of absolute alcohol. Complete solution did not take place until a further addition of 50 cc. of alcohol and 28 cc. of water had been made. Six grams of benzyl chloride, or one-half gram excess over the calculated, was then added and the mixture heated for three hours on the steam bath or until no alkaline reaction was obtained.

On evaporating the alcohol, a partially solidified mass remained. Part of this dissolved when warmed with dilute sodium hydroxide. The insoluble part formed a resinous semisolid on cooling; this gum could not be induced to crystallize.

From the alkaline solution acetic acid precipitated a mixture. This was boiled with about 50 cc. of alcohol. The portion which did not dissolve proved to be chiefly 4-methyluracil. On cooling the alcoholic solution, pearly, iridescent, diamond-shaped plates separated which melted about 220°–235°, at least 30° higher than 1-benzyl-4-methyluracil. Three crystallizations from alcohol raised the melting point to 233°–

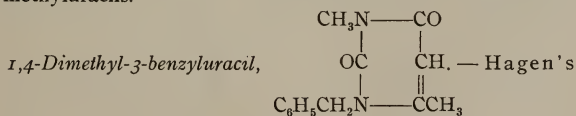
¹ *Loc. cit.*

235°. It therefore agreed with that given by Hagen for his benzyl-4-methyluracil. The compound is very difficultly soluble in hot alcohol and still more difficultly in boiling water. It is almost insoluble in cold chloroform. An analysis of the substance melting at 233°–235° gave results agreeing with those calculated for monobenzyl-4-methyluracil.

	Calculated for $C_{12}H_{12}O_2N_2$.	Found.
N	12.96	13.18

The alcoholic mother liquors from this were evaporated to dryness. The remaining material was then shaken with chloroform. The insoluble part proved to be almost pure 3-benzyl-4-methyluracil (Hagen's compound). The chloroform solution was evaporated to dryness and the residue was crystallized from alcohol, whereupon the isomeric 1-benzyl-4-methyluracil was obtained.

A second benzylation of 4-methyluracil, with 7 grams of the pyrimidine and two molecular proportions of potassium hydroxide (6.22 grams) and of benzyl chloride (14.5 grams) in 115 cc. of alcohol and 35 cc. of water, gave 3.6 grams of gum, insoluble in alkali, 2 grams of unaltered 4-methyluracil, and about 2 grams each of the isomeric nitrogen benzyl-4-methyluracils.



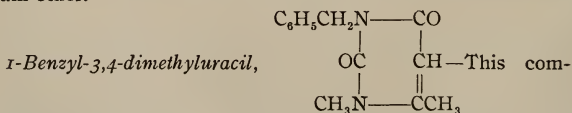
benzyl-4-methyluracil melting at 233° (1.6 grams) was dissolved in 90 cc. of methyl alcohol with three molecular proportions of potassium hydroxide and warmed for three hours and a half with methyl iodide (3.25 grams). The alcohol was then evaporated and the residue was stirred with dilute sodium hydroxide. This left 1.8 grams of oil which on cooling solidified. It was dissolved in ether and the clear, filtered solution was allowed to evaporate slowly in a tall test tube. Beautiful, clear, transparent, prismatic tables were then obtained which melted sharply at 85°–86°. When these

were mixed with 1,4-dimethyl-3-benzyluracil prepared by benzylating 1,4-dimethyluracil the melting point was not lowered. The two preparations agreed in all respects and are identical.

The preparation of this compound from 1,4-dimethyluracil was as follows: Two and eighty-five hundredths grams of 1,4-dimethyluracil and one molecular quantity of potassium hydroxide were dissolved in 120 cc. of 95 per cent alcohol. One molecular portion of benzyl chloride was added and the mixture was heated on the steam bath until a neutral reaction was obtained. A considerable amount of potassium chloride which separated was filtered off and the alcohol was evaporated, a partially solid mass remaining. A portion of this dissolved when treated with sodium hydroxide, leaving 2.1 grams of oil, which finally solidified. When crystallized from ether as described above it melted sharply at 85°-86° and the analytical results were as follows:

	Calculated for $C_{13}H_{14}O_2N_2$.	I.	Found.	II.
N	12.17	12.41		12.22

This substance was found to be extremely soluble in alcohol and benzene, much less so in ether, and only slightly in petroleum ether.



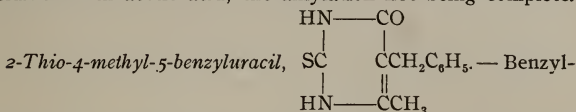
1-Benzyl-3,4-dimethyluracil,

long, colorless prisms melting at 164° to a clear oil, were obtained.

An analysis gave results agreeing with the calculated for 1-benzyl-3,4-dimethyl uracil.

	Calculated for $C_{18}H_{14}O_2N_2$.	I.	Found. II.
N	12.17	12.43	12.32

The alkaline solution above gave 1,4-dimethyluracil when acidified with acetic acid, the alkylation not being complete.



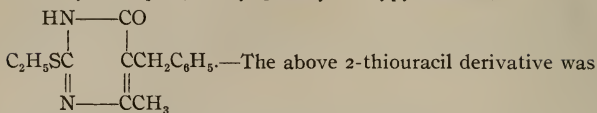
acetoacetic ethylester was prepared by the action of benzyl chloride upon the sodium salt of acetoacetic ester, according to the method of Ehrlich.¹ The portion boiling at 194° – 204° at 40 mm. pressure was used in the following work, part of which was done by Mr. McKay S. Howard:

Ten grams of benzylacetoacetic ester and 4 grams of thiourea were added to a solution of sodium ethylate made by dissolving three grams of sodium in 75 cc. of absolute alcohol. The mixture was heated on the steam bath for four hours. The alcohol was then evaporated and the residue was dissolved in water. On the addition of dilute acetic acid 2-thio-4-methyl-5-benzyl-6-oxypyrimidine was precipitated. The yield was 7.4 grams, or 70 per cent of the calculated. The substance was very difficultly soluble in water but more easily in alcohol, from which it crystallized in colorless, leafy plates or scales. After two recrystallizations it melted to a clear oil at 257° – 258° .

	Calculated for $C_{12}H_{12}ON_2S$.	I.	Found. II.
N	12.07	12.12	12.13

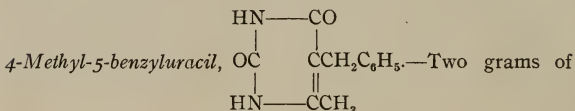
In another experiment, 20 grams of benzylacetoacetic ester gave 13.1 grams of the condensation product, or 62.4 per cent of the calculated.

¹ Ann. Chem. (Liebig), **187**, 12 (1875).

2-Ethylmercapto-4-methyl-5-benzyl-6-oxypyrimidine,

dissolved in alcohol containing one molecular proportion of sodium ethylate and then allowed to digest with a slight excess of ethyl bromide until the solution was neutral. The product, which was almost insoluble in water, and soluble only with difficulty in cold alcohol, formed fine, prismatic needles melting sharply at 166°.

	Calculated for $\text{C}_{14}\text{H}_{16}\text{ON}_2\text{S}$.	I.	Found.
N	10.77	11.00	II. 10.56



the above mercapto compound were allowed to digest for 24 hours on the steam bath with 50 cc. of concentrated hydrochloric acid. Mercaptan escaped, and, on cooling, 1.6 grams of 4-methyl-5-benzyluracil, or 96 per cent of the calculated, separated. The substance was recrystallized from water and alcohol. It gave diamond-shaped plates melting to a clear oil at 249°–250°.

	Calculated for $\text{C}_{12}\text{H}_{12}\text{O}_2\text{N}_2$.	Found.
N	12.96	13.06

2-Benzylmercapto-4-methyl-5-benzyl-6-oxypyrimidine.—This was prepared by benzylating 2-thio-4-methyl-5-benzyluracil with molecular quantities of benzyl chloride and sodium ethylate in alcoholic solution. It is nearly insoluble in water. From alcohol it separates in matted masses of long, colorless needles and it melts to a clear oil at 194°.

	Calculated for $\text{C}_{19}\text{H}_{18}\text{ON}_2\text{S}$.	I.	Found.
N	8.69	8.58	II. 8.75

This benzylmercapto compound proved to be very stable when boiled with hydrochloric acid. It was not desulphurized when given the same treatment as that in the case of the corresponding ethylmercapto derivative. When boiled with hydrobromic acid it was finally desulphurized and 4-methyl-5-benzyluracil was obtained. In view of this behavior it is therefore not a matter of indifference what mercapto derivative is chosen for these desulphurizations.

NEW HAVEN, CONN.,
May, 1909.

ON THE THEORY OF INDICATORS AND THE REACTIONS OF PHTHALEINS AND THEIR SALTS.

BY S. F. ACREE AND E. A. SLAGLE.

[THIRD COMMUNICATION ON THE TAUTOMERISM OF PHTHALEINS.¹]

(We are indebted to the Carnegie Institution of Washington for aid in our work on tautomerism.)

The rapid advance in our knowledge of the constitution and reactions of colored compounds of the aromatic series has made it clear that we must seek the cause of the manifestation of color in some deep-seated change in the molecule itself. The view formerly held that the color of these particular benzene derivatives is a function only of the increase in the molecular weight, or depends upon the introduction of certain elements or groups which tend to produce color, has long been abandoned.

The first important attempt to formulate a theory of color is seen in the hypothesis of O. N. Witt,² brought out in 1876, in which he assumed in all colored compounds the presence of certain specific groups (nitro, azo, cyan, etc.) which were thought to be responsible for the color. Witt called these groups *chromophores*. He recognized in some cases the additional influence of certain salt-forming groups (hydroxyl, amino, etc.) which intensify the color of the chromophore

¹ THIS JOURNAL, **37**, 71; **39**, 528, 789.

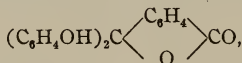
² Ber. d. chem. Ges., **9**, 522.

and give to the compound the properties necessary in making the dye practically useful. These latter groups were called *auxochromes*.

The quinone theory was first advanced by E. and O. Fischer to explain the colors of the dyestuffs of the rosaniline series and is really an extension of Witt's, which gives a more definite meaning to the term *chromophore*.

In 1889 Nietzki¹ extended the quinone theory, using, however, the modern formula of quinone, to the indamine and azin series. This conception was shortly after extended by Armstrong to include all colored compounds of the aromatic group.

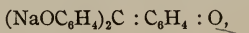
In 1893 Friedländer² assigned a corresponding quinone structure to phenolphthalein salts. He accepted Baeyer's formula for phenolphthalein in the free condition,



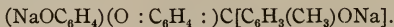
but assumed that an intramolecular change takes place in the molecule in the presence of alkalis which results in the formation of the colored quinone salt,



which he assumed to be analogous to the salts of aurin,



and of rosolic acid,



As a proof of the existence of the quinone structure in the salt



he prepared an oxime by treating an alkaline solution of phenolphthalein with hydroxylamine. Friedländer also suggested that phenolphthalein is a dibasic acid and that the salts are dibasic salts, but it remained for Meyer and Spengler³ to prove

¹ Organische Farbstoffe, 1st Edition, p. 2.

² Ber. d. chem. Ges., 26, 172.

³ Ibid., 38, 1318.

this by isolating and analyzing the salt $C_{20}H_{12}O_4Na_2$. At about the same time Bernsthen¹ came to similar conclusions in his researches on rhodamine 6 G and suggested that fluorescein exists in the free condition as the lactone compound but has the quinone structure in its salts.

A few years ago another conception of the cause of color was advanced by Baeyer² and called by him *halochromy*. He assumed the existence, in colored bodies of the triphenylmethane series, of a peculiar form of valence represented by a wavy bond, $C \sim Cl$, which Baeyer and Villiger called the *carbonium valence*. In this condition carbon was assumed to act as a strongly basic element which brings about the manifestation of color. This theory has recently been given up by Baeyer.

In 1890 Ostwald³ proposed an explanation of color changes based on the theory of electrolytic dissociation. He assumed phenolphthalein to be an extremely weak acid and consequently but little dissociated; on the addition of an alkali a salt is formed which is largely dissociated, and the red color was thought to be due to the anion. The work on the physical constants of phenolphthalein has shown that a close quantitative relationship exists between Ostwald's theory and color change, yet many facts make it evident that this theory is in itself not able to account for all of the known phenomena. While it is true that the negative ions are colored, the change in color is due to a change in constitution of the compound, the ions having a structure different from that of the mother substance.

In 1903 Stieglitz⁴ published a valuable article on the theory of indicators. By the use of (a) the evidence on the quinone theory furnished by Friedländer and Nietzki, (b) Hantzsch's ideas and equations concerning pseudoacids, and (c) Ostwald's conception of the quantitative relationships in the indicator work, Stieglitz came to the conclusion, in con-

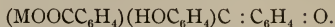
¹ Chem. Ztg., **1892**, 1956.

² Ber. d. chem. Ges., **38**, 570, 1156.

³ Lehrbuch der allgemeinen Chemie, **1891**, p. 462; Scientific Foundations of Analytical Chemistry, 1890.

⁴ J. Am. Chem. Soc., **25**, 1112.

sidering phenolphthalein, that (p. 1115) "its red salts are the salts of a carboxylic acid, *not a phenol*, and have the constitution



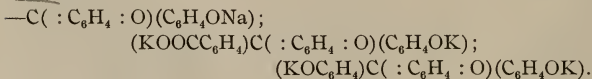
The strongly chromophoric quinoid complex (: C₆H₄ : O) gives us an explanation of the production of intense color, which is entirely adequate in view of the laws governing color in organic compounds." After developing the equation

$$C_Q \times C_H = K'' \times C_{LH}$$

for the affinity constant of the phenolphthalein he stated (p. 1122) that "its tendency to produce *the red color (the red salt)*¹ is measured by the same constant *K''*." Hantzsch² points out that he too had proposed this theory.

In 1905 Meyer and Spengler³ published a very important article in which they showed that the colored salts of phenolphthalein are dibasic salts, but they discarded the quinone hypothesis and accepted Baeyer's theory of halochromy.

In May, 1906, Acree and Brunel⁴ began an investigation on indicators as a part of their work on tautomerism. It was seen by them that previous theories did not account fully for either the color phenomena or the alkylation reactions of aurin, phenolphthalein, fluorescein, etc., and they began work on these substances from the point of view that the tautomeric mono- and dibasic phenol and carboxyl salts are concerned in the alkylation reactions and in the color phenomena. It was seen, for instance, as had already been surmised by Friedländer,⁵ that *the chief source of color in the salts of aurin, phenolphthalein, etc., is not the quinone group* assumed by practically all of the other workers, but a *quinone-phenolate group*,



¹ All the italics and words in parentheses are ours for emphasis.

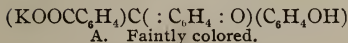
² Ber. d. chem. Ges., **39**, 1090. Rohland: *Ibid.*, **40**, 2172.

³ *Ibid.*, **38**, 1318.

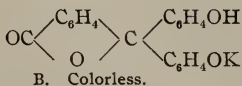
⁴ THIS JOURNAL, **37**, 71. See also *Ibid.*, **27**, 118; **31**, 185; **32**, 606; **37**, 361; **38**, 1; **39**, 124, 226; Ber. d. chem. Ges., **35**, 553; **36**, 3139; **37**, 184, 618; **41**, 3199.

⁵ Ber. d. chem. Ges., **26**, 172.

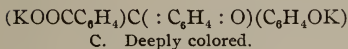
It was clear that the four possible mono- and dibasic salts, A, B, C and D, must be represented as follows:



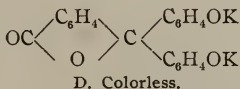
A. Faintly colored.



B. Colorless.

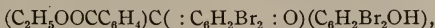


C. Deeply colored.



D. Colorless.

The compound A, assumed by others to be the colored salt of phenolphthalein, can give only faintly colored solutions, the carboxylphenoldibasic salt, C, being the salt really chiefly responsible for the color changes. B and D were thought to be colorless, as are the corresponding esters. This was perfectly apparent from the work of Nietzki and Burckhardt and Schroeter¹ on the fluorescein and phenolphthalein derivatives, and from the long known work on rosolic acid and aurin, which was pointed out by Friedländer; but the significance of these facts was unfortunately entirely overlooked by the other workers who referred to these articles, a fact which shows that even the most brilliant human minds are very imperfect instruments for aiding us to interpret nature's phenomena. The faintly colored carboxyl ester of tetrabromphenolphthalein, which is already a quinone,

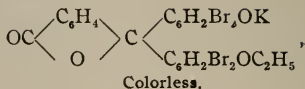
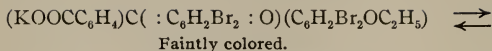


forms a deeply colored blue potassium or silver salt,

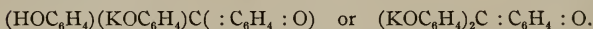


On the other hand, the isomeric phenol ester, which according to the quinone theory should yield deeply colored salts, gives practically colorless salts,

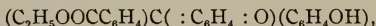
¹ Ber. d. chem. Ges., 28, 48; 30, 178.



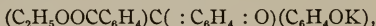
because no quinonephenolate group can be formed. Especially, though, was this point made clear by the properties of aurin, $(\text{HOC}_6\text{H}_4)_2\text{C}(:\text{C}_6\text{H}_4:\text{O})$. This compound has already a quinone group, and yet when alkali is added to an aqueous solution of the substance there is formed an intensely colored salt,



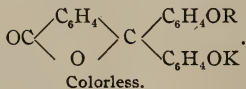
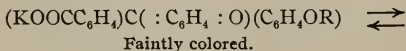
These reactions were sufficient to show us that the quinone theory alone can not account for the color phenomena. Our view has been recently confirmed more fully by the fact observed by Green and King¹ that the faintly colored carboxyl ethyl ester of phenolphthalein, itself a quinone derivative,



yields the intensely colored *quinonephenolate salt*,



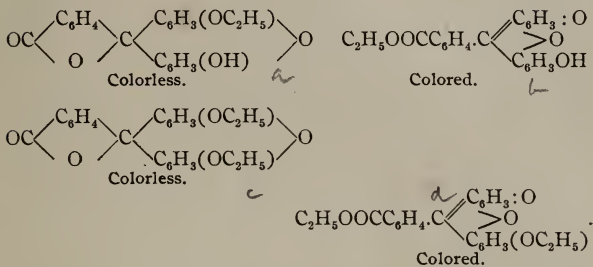
whereas the isomeric phenol ethyl ester of phenolphthalein, which *can* form a quinone, but not a quinonephenolate, yields a colorless salt:



The evidence is just as strong that both phenol and carboxyl salts must be concerned in the alkylation reactions. Nietzki and Schroeter found that their "Fluorescein Kalium" and ethyl bromide gave the isomeric colorless phenol and col-

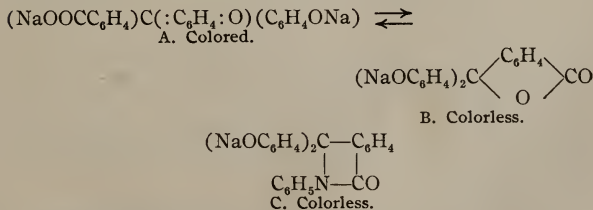
¹ Ber. d. chem. Ges., **40**, 3724.

ored carboxyl monoethyl esters, and the isomeric colorless diphenol diethyl ester and colored carboxylphenol diethyl ester:



These esters seemed from the description given to be stable compounds which did not rearrange, and from Acree's theory of tautomeric compounds it seemed hardly likely that they were formed from tautomeric monobasic salts, but altogether probable that they were obtained from tautomeric dibasic fluorescein salts. Likewise alkylation experiments by Haller and Guyot¹ and by Herzog and Meyer² with phenolphthalein salts yielded 85 to 90 per cent of the colorless lactone dimethyl ester, whereas Orndorff³ found that gallein yields both quinone and lactone esters.

Both the color phenomena, then, and the alkylation reactions pointed to the presence and reactions of tautomeric dibasic salts:



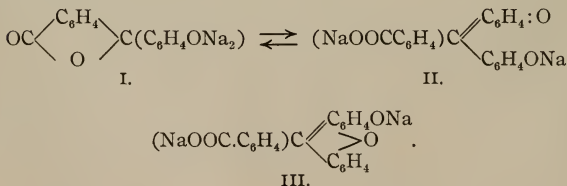
¹ Compt. Rend., 120, 296.

² Ber. d. chem. Ges., 28, 3258.

³ THIS JOURNAL., 31, 97.

We believed that A is intensely colored, but that salts analogous to B are colorless, just as the corresponding salts of the anilides,¹ C, are without color. But we thought that by "Fluorescein Kalium" Nietzki and Schroeter perhaps meant the *monopotassium* salt, and if this had been true it would have been very unfortunate for our theory. We accordingly ordered some "Fluorescein Kalium" from Hoeschst and Company and the analysis proved that it contained more than 3 atoms of potassium to one molecular quantity of the salt. There was evidently, therefore, justification for a continuance of the problem from our point of view of tautomeric salts, but the work was given up on account of the departure of Dr. Brunel from this laboratory.

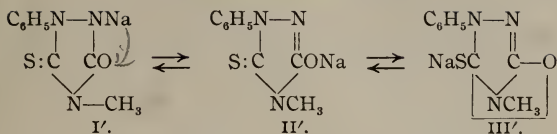
In the meantime, other work was appearing which had a very direct bearing on this problem. From a large number of investigations it appeared probable to us that we might have not only the quinoid and lactoid dibasic salts concerned in the colors, but also still another tautomeric salt, an intramolecular condensation product of the phenol salt with the carbonyl of the quinone group, which indeed seemed to be the chief source of color in such compounds:



In work begun in 1902, Acree² obtained evidence that the 1-phenyl-3-oxy-4-methyl-5-thiourazole and its salts could exist not only in the two tautomeric forms, I'. and II', ordinarily assumed, but also in still another intramolecular form, III', analogous to III.:

¹ Meyer and Spengler: Ber. d. chem. Ges., **36**, 2949.

² THIS JOURNAL, **31**, 187; **32**, 606. Nirdlinger: Dissertation, Johns Hopkins University, 1909.



Busch and Opfermann¹ later actually isolated the corresponding 1,4-diphenyl-5-thiourazole acids, and Busch and Reinhardt² showed that the salts can exist. Acree and Nirdlinger have now made these tautomeric salts and actually proved quantitatively that one of them has the properties expected of a compound having the structure III'. Although these salts are not visibly colored yet they will without doubt be found to have different colors outside the visible spectrum, as do many other such compounds (Baly, Hardley, Keyser, etc.). The actual isolation of III'. proves the possible existence of the analogous substance III., and as long ago as 1904³ we pointed out that such intramolecular salts must be considered in addition to the ordinary forms.

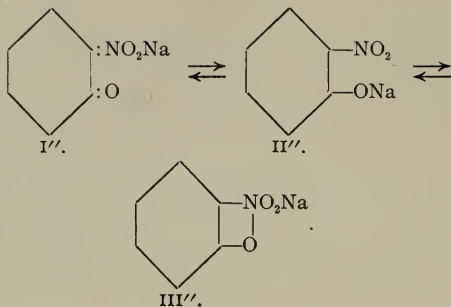
Hantzsch,⁴ in working on this problem of the cause of color in salts, had to assume, as we were doing, that both forms of the tautomeric acids are ionized, and consequently had to give up his former idea that a tautomeric acid exists in two forms, one of which, the pseudoacid, is not ionized, while the other, the "echt" acid, is dissociated. This led him then to assume the presence of two salts in equilibrium, as we have been doing, instead of the one salt, that of the "echt" acid. But a new idea advanced by him was that there were not only *two* tautomeric salts of nitrophenol, for instance, but also another intramolecular salt, III'', analogous to III., with a different color and different properties:

¹ Ber. d. chem. Ges., **37**, 2333.

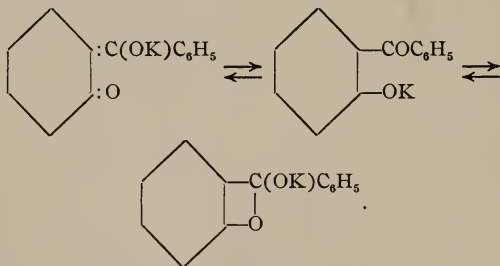
² Reinhardt: Dissertation, Erlangen, 1906.

³ THIS JOURNAL, **31**, 187; **32**, 606, footnote.

⁴ Ber. d. chem. Ges., **39**, 1084; **40**, 333.



In another case Hantzsch¹ assumed the presence of such an intramolecular salt, analogous to III. He found that oxybenzaldehydes and oxybenzophenones yield different colored salts to which he gave the formulas



The chief reason, however, for believing that an intramolecular salt, III., is probably the chief source of color in the phenolphthalein series came from work by Jackson² and his coworkers, by Wichelhaus³ and by Posner.⁴ Jackson and Oenslager⁵ and Clarke,⁶ and also Wichelhaus, showed

¹ Ber. d. chem. Ges., **39**, 1084, 3080; **40**, 335, footnote, etc.

² Their articles did not bear especially on indicators.

³ Ber. d. chem. Ges., **5**, 849.

⁴ Ann. Chem. (Liebig), **336**, 85.

⁵ THIS JOURNAL, **18**, 1.

⁶ *Ibid.*, **34**, 441.

that when a quinone adds sodium phenolate or sodium β -naphtholate, or dimethylaniline, the intensely colored double salts,



are formed in *nonaqueous* solvents. Posner ascribed to these compounds different constitutions, but that question does not affect our theory. It was therefore a question to be decided by experiment whether the quinone group and the sodium phenol group of II. might not also combine to form a deeply colored salt, III., even in *aqueous* solutions. But it was clear that the experiments would actually have to be done in aqueous solutions, in which the color changes of phenolphthalein manifest themselves, especially as Jackson found the quinonephenolate addition products to be decomposed by water.¹

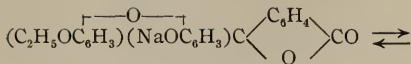
In a similar way it is clear that the phenol ester salt B, p. 126, can not be deeply colored. Since the phenol *esters* do not unite with quinones at all, the color of B is simply that of the quinone group.

If our theory of tautomeric salts is to explain the alkylation reactions and the color changes of phenolphthalein, etc., correctly, three things must be proved *quantitatively*, and to this part of the problem we have now devoted ourselves.

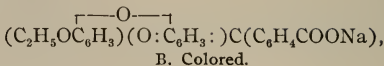
I. It must be proved by experiment that fluorescein forms the tautomeric dibasic salts, each of which yields, to some extent, its corresponding ester in independent side reactions, no ester being formed entirely by a rearrangement of another ester.

We have now been able to do this in a clear-cut way, as is brought out fully in the experimental portion. The phenol ethyl ester of fluorescein, for instance, forms a monosodium salt which is colored and which exists in the two forms in equilibrium with each other:

¹ Jackson and Oenslager: *THIS JOURNAL*, **18**, 16, 20.

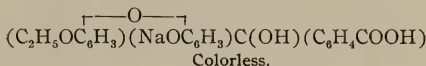


A. Colorless.

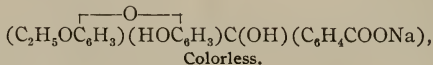


B. Colored.

and with their hydrated forms,



Colorless.

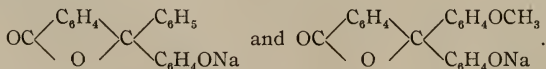


Colorless.

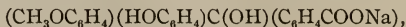
and perhaps with the intermolecular salts.

That there is not simply one salt, B, is proved by the fact that this sodium salt and ethyl iodide yield *two* diethyl esters, the colored quinone ester corresponding to B and the colorless diphenol ester corresponding to A. These esters do not rearrange into each other under the conditions of the experiment and hence at least two tautomeric salts must be present.

This theory of tautomeric salts accounts very nicely also for the *lack of color* in some of these salts. Such substances as *p*-oxydiphenylphthalid,¹ the phenol ethyl ester of phenolphthalein,² and the corresponding phenol ester of tetrabromophenolphthalein,³ dissolve in alkalies without color. Since each of these compounds yields *only* the corresponding lactone ester we believe that the salts have to some extent the lactoid form,



This may be in equilibrium with the hydrated form,

¹ Baeyer: Ann. Chem. (Liebig), **354**, 171.² Ber. d. chem. Ges., **40**, 3728.³ *Ibid.*, **30**, 177.

which Green and King¹ assumed to be the structure of all these colorless salts. But we do not think that this point of view of Green and King accounts for the formation of nearly quantitative yields of the phenol dimethyl ester from methyl iodide and the sodium salts of phenolphthalein and hydroquinonephthalein, of the phenyl methyl ester of dibrom-*p*-oxydiphenylphthalid from the sodium salt and methyl iodide, or for the formation of *both* isomeric esters of fluorescein obtained by us: our theory does account for these facts. Since Green and King assume the presence of a hydrated *carboxyl salt* we should certainly expect to obtain some carboxyl ester if their theory is correct; but no carboxyl ester is formed, apparently, from the colorless salts mentioned above. It is unfortunate that no one has isolated these colorless salts and shown by analysis whether they are hydrated and become colored when dehydrated, or whether the carboxyl esters rearrange into phenol esters. That these salts may actually exist in the lactoid form is proven, it seems to us, by the fact that Meyer and Spengler² actually made the colorless lactoid salts of the anilides of phenolphthalein and hydroquinonephthalein. This is a very important phase of our work and it will be continued in this laboratory from several points of view.

II. It must be proved that these *quinonephenolate double salts* of Jackson and Oenslager and of Wichelhaus and the *quiaminones* of Jackson and Clarke are formed in *aqueous solutions*. If these were decomposed completely into their constituents in water, it is evident that these substances could not be concerned in the color changes of indicators and dyestuffs as they are ordinarily used. We³ have fortunately been able to prove that deeply colored compounds are formed by the union of benzoquinone or anthraquinone with salts of *o*-cresol, *p*-cresol, phenol, hydroquinone, pyrogallol and resorcinol, the colors of which disappear when acids are added. In fact such mixtures serve as very good indicators. Likewise, dimethylaniline or α -dimethylamino-

¹ J. Chem. Soc., **85**, 398; Ber. d. chem. Ges., **40**, 3724.

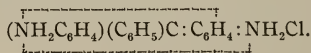
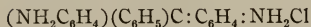
² Ber. d. chem. Ges., **36**, 2949.

³ Acree and Slagle: THIS JOURNAL, **39**, 534, 535.

α -bromnaphthalene and quinone form intensely colored *quinaminones* in aqueous solutions, the color of which fades to that of the quinone when the amine is converted into the salt.

This idea is further borne out by the fact that Bistrzycki's diphenylquinonemethane,¹ which can not form the quinone-phenolate salt, $(\text{C}_6\text{H}_5)_2\text{C} : \text{C}_6\text{H}_4 : \text{O}$, is far less deeply colored than the salts of benzaurin, $\text{C}_6\text{H}_5\text{C}(\text{C}_6\text{H}_4 : \text{O})(\text{C}_6\text{H}_4\text{ONa})$, or aurin, $(\text{NaOC}_6\text{H}_4)_2\text{C} : \text{C}_6\text{H}_4 : \text{O}$, which can form the intramolecular, deeply colored quinonephenolate group.

Further evidence is furnished by the brilliant work of Baeyer,² who showed that salts of *p*-aminotriphenylcarbinol, $(\text{C}_6\text{H}_5)_2\text{C} : \text{C}_6\text{H}_4 : \text{NH}_2\text{Cl}$, which can not form a *quinaminone*, are only light orange in color, whereas the *p,p*-diaminotriphenylcarbinol gives salts having an intense violet color because it forms, to some extent, the deeply colored *quinaminone* group:



When an excess of acids is added to fuchsin or to malachite green³ the colors fade because the acid converts the amino group into a salt which can not form the *quinaminone*.

III. The equations and ideas used by Hantzsch and Stieglitz to express the affinity constant of the indicator and the tendency to form the colored salts are not complete⁴ and have been replaced by those developed by Acree⁵ to show the relations between the equilibrium constants and the affinity constants of the several tautomeric forms of the acid. These equations have been tested experimentally in the urazole series by Acree and Shadinger⁶ and found to hold, and

¹ Ber. d. chem. Ges., **36**, 2337.

² Ann. Chem. (Liebig), **354**, 161-2.

³ Acree and Slagle: THIS JOURNAL, **39**, 536.

⁴ Acree: *Ibid.*, **39**, 529. Stieglitz: *Ibid.*, **39**, 652. Wegscheider: Z. Elek. Chem., **34**, 510. Hildebrand: J. Am. Chem. Soc., **30**, 1717.

⁵ THIS JOURNAL, **38**, 11, *et seq.*, and many subsequent articles.

⁶ *Ibid.*, **39**, 124.

see errata
p. 374

similar ideas are also being used by Wegscheider. A great deal of quantitative work will be necessary to clear up all of these problems connected with the indicators. *The cause of the color¹ is probably the inter- or intramolecular change of the various salts into each other, as has been brought out thoroughly by Hartley and Baly.²*

In the last year or two a number of others have begun work from our point of view that the chief source of color is not the quinone group but a quinonephenolate group, and that the most important source of the color is probably the intramolecular salt formed by the union of the quinone and the phenolate or aniline derivative. In 1907, Baeyer³ published a long and valuable article on the dyestuffs, in which he gave up his theory of halochromy in favor of the quinone theory, discussing fully his reasons for doing so. He proposed this quinonephenolate theory and tested it by treating fuchsone and fuchsoneammonium chloride with sodium phenolate and dimethyl-*p*-toluidine, but no colors were obtained. Our experiments, however, gave beautiful color changes.

Stieglitz⁴ has also given up his former point of view and now has proposed the quinhydrone hypothesis as a cause of the color changes, including the salts as well.

Willstaetter and Piccard,⁵ at about the same time, brought out in a valuable contribution the same quinhydrone hypothesis and applied it in a number of directions.

Recently K. H. Meyer⁶ has discussed some of the recent work and ideas and prepared a number of compounds.

Since Acree's first paper was published R. Meyer⁷ has presented an important article in which he has changed from Baeyer's theory of halochromy to the quinonephenolate theory which we are using.

Wegscheider⁸ too has recently taken up the study of phenol-

¹ THIS JOURNAL, **39**, 537.

² J. Chem. Soc., **85**, 1029; **89**, 502, 514; **91**, 426, 1572.

³ Ann. Chem. (Liebig), **354**, 162.

⁴ THIS JOURNAL, **39**, 651.

⁵ Ber. d. chem. Ges., **41**, 1458.

⁶ Ibid., **42**, 1149.

⁷ Ibid., **41**, 2446.

⁸ Z. Elek. Chem., **34**, 510.

phthalein from a similar point of view and has obtained results in harmony with our theory.

It is evident then that a number of men have been engaged on work which led them to the same general point of view, which is a very great advance in the theory of indicators and dyestuffs. We do not claim any credit for the very important view advanced by Baeyer, Stieglitz, and Willstaetter that *quinhydrones*, as they are always defined, are concerned in the colors of the free acids. But we do believe that our theory of tautomeric salts accounts more fully for the *colors* of the *salts* and their *alkylation reactions* than the theory of any other workers, and since the salts are the substances of chief importance in the colors and reactions of dyestuffs, the free acids or bases being comparatively insignificant in this respect, we shall continue to devote our attention chiefly to this phase of the subject.

A study of the affinity constants of the indicators from our point of view, of the influence of alcohol in decolorizing the salts, of the influence of salts and acids in intensifying the colors of the dyestuffs,¹ and other problems mentioned in our first article are of very great importance. The salts of weak bases, such as SnCl_2 , AlCl_3 , etc., and also acids, seem to form deeply colored double compounds with a number of quinoid and lactoid derivatives. We suspect that in all such cases the basic properties of the oxygen of a quinone group are directly concerned.

FLUORESCEIN.

The melting point method can not be used as a criterion of the purity of fluorescein. It decomposed above 290° without melting. Every precaution was therefore taken in the preparation to obtain a pure substance. Pure phthalic anhydride and pure resorcinol were heated with zinc chloride at 180° . The product was obtained free from resorcinol by washing with several liters of cold water, and was then dissolved in a solution of sodium carbonate and precipitated by sulphuric acid. The fluorescein obtained in this way is

¹ K. H. Meyer: Ber. d. chem. Ges., **41**, 2568. Meyer and Hantzsch: *Ibid.*, **40**, 3479.

bright yellow in color. After it is crystallized a number of times from alcohol it becomes dark red, a darker red than sulphophenolphthalein. When the yellow product is heated in an air bath for five hours at 115° it shows no appearance of red whatever. This bright yellow color is retained even after standing in a glass-stoppered bottle eighteen months.

The Four Ethyl Esters of Fluorescein.

The four ethyl esters of fluorescein were obtained by dissolving fluorescein in alcoholic sodium hydroxide, adding ethyl iodide, and heating under a reflux condenser on the water bath. Different amounts of fluorescein, solvent, and halide were used and the time of alkylation varied from four to twenty-four hours. No definite conclusions were reached as to the amounts of the different esters formed under the different conditions. The best yield of esters, however, was obtained by continuing the alkylation eight hours.

After the reaction was over any excess of ethyl iodide was expelled by evaporation and the product was poured into cold water, whereupon the two diethyl esters were precipitated. These were then filtered and carbon dioxide was passed into the filtrate. This precipitated the two monoethyl esters.

The only method found for separating the two monoethyl esters was fractional crystallization from dilute alcohol. After repeated crystallizations the colored carboxyl ester, somewhat more soluble in dilute alcohol than the colorless phenol ester, was obtained with a constant melting point 247° . The colorless phenol ester was found to melt, when pure, at 251° .

The colored diethyl ester was separated from the colorless diethyl ester also by fractional crystallization from dilute alcohol. When pure, the colorless diethyl ester melts at 182° , and the colored diethyl ester at 159° .

As stated above, Herzig and Pollak, on methylating fluorescein salts with *methyl iodide*, obtained chiefly the lactoid esters. We have found, in general, that *ethyl iodide* also produces the lactoid esters in excess, although the ratio of the lactoid to the quinoid varies greatly with the conditions of the experiment and time of alkylation. Quite different

results were obtained with *diazomethane*; Herzig and Pollak obtained with this reagent chiefly the quinoid esters.

We have found that *diazoethane* yields, with an excess of either the red and yellow fluorescein, only the colored quinoid diethyl ester. The product of the reaction, without purification, melts at 157° , only two degrees below the melting point of the pure ester, 159° . When this ester is crystallized from glacial acetic acid it gives the proper melting point.

Preparation of the Pure Sodium Salt of the Phenol Ethyl Ester of Fluorescein.

The pure sodium salt of the phenol ethyl ester was prepared by agitating an excess of the ester with a solution of sodium hydroxide and then filtering the undissolved ester. The filtrate was shaken again with a little of the ester and filtered. The filtrate was extracted with carbon tetrachloride and then evaporated to dryness on the water bath. There is no loss in weight on evaporating this salt to dryness on the water bath, although some of the esters are slightly volatile under these conditions.

The sodium salt of the phenol ester dissolves in water with a color much less intense than that of the fluorescein salt, and in ethyl and methyl alcohol with a very faint color at temperatures from -15° to 0° . This color increases very decidedly as the temperature is raised to 80° , but decreases again as the temperature is lowered.

An attempt was made to study the velocity of ester formation; the equation for the reaction is that of the second order,

$$\frac{x}{t(A-x)} = AK.$$

The concentrations of the sodium salt and ethyl iodide were 0.3 weight normal and volume normal, respectively, in 40 per cent alcohol.

The solution was sealed in a tube and heated in a constant temperature bath at 60° .

In the following table t gives the time in hours, A the number of grams of salt taken, x the amount of ester formed,

and $A-x$ the amount of unchanged salt. AK is the constant calculated for a bimolecular reaction.

t .	A .	$A-x$.	x .	AK .
2	0.382	0.3169	0.0651	0.10
3	"	0.3053	0.0767	0.19
4	"	0.2492	0.1328	0.13
7	"	0.2028	0.1792	0.12
(17)	"	0.0190	0.3630	0.11
(24)	"	0.0544	0.3276	(0.25)

The divergence of AK from a constant value is due to the difficulty in obtaining quantitative methods of separation and analysis.

We found that on ethylating the sodium salt as above, a mixture of the colorless phenol diethyl ester and the colored quinone diethyl ester is formed. To separate and identify these esters we boiled the alkylation product about three hours in alkali, which saponified the colored quinone diethyl ester. The solution was then filtered, the filtrate acidified, the phenol ethyl ester extracted with carbon tetrachloride, and identified by its melting point, 247° .

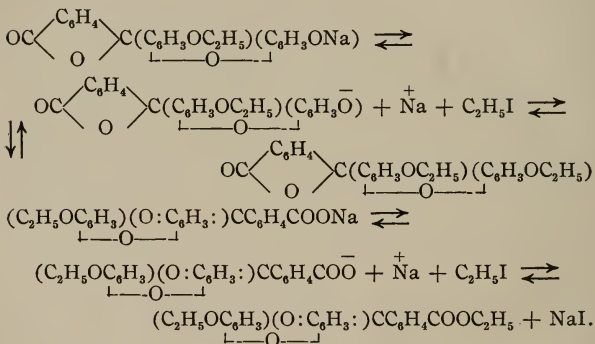
The unsaponified colorless phenol diethyl ester was collected from the filter and identified by the melting point, 251° .

In order to determine whether any rearrangement of the esters took place under the conditions of the experiment, we dissolved 0.0524 gram of the colorless phenol ester and 0.5500 gram of the colored quinone ethyl ester in 5 cc. of 40 per cent alcohol with ethyl iodide in 0.3 N solution of 40 per cent alcohol and heated the mixture a number of hours in a sealed tube in the bath at 60° . The tube was then opened and after separation 0.0516 gram of the colorless phenol ethyl ester and 0.5494 gram of the colored quinone ethyl ester were recovered. We then dissolved 0.6024 gram of the sodium salt of the phenol ethyl ester, 0.0316 gram of the colorless phenol ethyl ester, and 0.1702 gram of the colored quinone ethyl ester in 40 per cent alcohol, sealed this solution in a tube, and heated at 60° for six hours. The tube was then opened and the esters extracted from the salt. After

the separation 0.0306 gram of the colorless phenol ethyl ester and 0.1698 gram of the colored quinone ethyl ester were recovered.

Conclusions from the Alkylations.

Since the colorless phenol diethyl ester and the colored quinone diethyl ester are formed from the sodium salt of the phenol ethyl ester and since we have found that no rearrangement takes place under the conditions of the experiment, the equilibrium and reactions can be expressed as follows:



The equilibrium is assumed to be between the molecular forms of the salts because the evidence obtained in work on the urazoles seems to point in this direction. The same is true of the assumption of a reaction between the alkyl halide and the anions of the salt. We have shown in work in other fields that reaction mechanisms are sometimes very complex and we do not commit ourselves finally as to the above assumptions.

PHENOLPHTHALEIN.

Phenolphthalein was obtained quite pure, melting at 254°, by the method of McCoy.¹

¹ THIS JOURNAL, 31, 507.

The attempt to obtain the four esters of phenolphthalein in sufficient quantity and purity by direct alkylation of phenolphthalein in alkaline solution with ethyl iodide proved fruitless. The potassium salt of phenolphthalein was treated with sulphonyl chloride. The reaction was vigorous, sulphur dioxide being evolved. The product of the reaction, resembling tar, was readily soluble in ether and gave a purple color with alkali but was not obtained pure.

TETRABROMPHENOLPHTHALEIN.

Since the tetrabromphenolphthalein and its derivatives were more readily obtained pure, attention was directed to them.

Phenolphthalin was prepared according to the directions of Baeyer.¹ This can be obtained quite free from phenolphthalein by crystallization from boiling water: 100 parts of water dissolve at 20° 0.0175 parts of phenolphthalin. When pure it melts at 225° and dissolves in alkali entirely without color. It is not changed appreciably on standing, but by prolonged heating in air it is oxidized to phenolphthalein.

In all of the following solubility experiments a known quantity of the acid or ester was shaken in a machine with a known quantity of alkali, not sufficient for solution, at 20°, for a number of hours. The undissolved acid or ester was filtered and weighed. The filtrate was acidified and the precipitated material also weighed as a check.

Meyer and Spengler² found that the unsubstituted phthalins neutralize two molecular equivalents of alkali. Our results with the phthalins verify this. But the phthalins require, in general, somewhat less than two molecular equivalents of alkali, instead of the calculated three molecules, a proof that the phthalins are much weaker acids whose salts are more greatly hydrolyzed. Since we expect to measure the affinity constants of a large number of these dyestuffs a preliminary study of the hydrolysis constants through a de-

¹ Ann. Chem. (Liebig), **202**, 80.

² Ber. d. chem. Ges., **38**, 1327.

termination of the solubilities of these substances in alkalis seemed desirable.

Solubility of Phenolphthalin in Alkali.

Amount of acid dissolved.	Calculated cc. of 0.1 N NaOH, one molecular equivalent to one of acid.	cc. of NaOH required.
1.3205	41.3	29.22
0.4901	15.3	10.78

The small amount of alkali required for the solution of phenolphthalin can be explained by the formation of an acid salt in solution.

We prepared tetrabromphenolphthalin by Baeyer's method.¹ It crystallizes from benzene in colorless short needles which melt at 208°–209°. When exposed to the light in a glass-stoppered bottle for several months it becomes colored light pink, without, however, any change in the melting point.

Solubility of Tetrabromphenolphthalin in Alkali.

Amount of acid dissolved.	Calculated cc. of 0.1 N NaOH, two molecular equivalents to one of acid.	cc. of NaOH required.
0.7614	9.12	7.48
0.4731	7.06	5.49

It appears from this experiment that an acid salt is formed in this case.

The carboxyl ester of phenolphthalin was obtained by passing hydrogen chloride into an alcoholic solution of the acid. This ester crystallizes from dilute alcohol in colorless leaves which melt at 157°–158°. The ester is quite stable, being saponified only to a slight extent by standing overnight in a ten per cent solution of sodium hydroxide.

The carboxyl ester of phenolphthalin was brominated by dissolving it in glacial acetic acid and adding bromine. The tetrabrom product crystallizes from glacial acetic acid and melts at 164°.

¹ Ann. Chem. (Liebig); **202**, 85.

Solubility of the Carboxyl Ethyl Ester of Tetrabromphenolphthalin in Alkali.

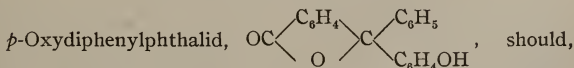
Amount of acid ester dissolved.	Calculated cc. of 0.1 N NaOH, two molecular equivalents to one of acid ester.	cc. NaOH required.
0.4804	14.46	15.95
0.3160	9.52	10.58

We found that potassium dichromate had no oxidizing effect on this ester. Potassium permanganate and potassium ferricyanide readily oxidize it to the salt of the carboxyl ester of tetrabromphenolphthalein. The free ester was not obtained from this salt in sufficient quantity and purity for the investigation.

We prepared *p*-oxy-*o*-benzoylbenzoic acid according to Friedländer's directions,¹ and the carboxyl ethyl ester by passing hydrogen chloride into the alcoholic solution. The ester crystallizes from glacial acetic acid as a white crystalline powder melting at 115°.

We attempted to bring about the condensation of this ester with phenol in the presence of zinc chloride and also of concentrated sulphuric acid in order to obtain the carboxyl ethyl ester of phenolphthalein, but were unsuccessful.

The attempt to prepare the silver salts of the carboxyl ethyl ester of phenolphthalein and the carboxyl ethyl ester of tetrabromphenolphthalein proved a failure. A water solution of silver nitrate was added to a water solution of each salt at 0° in a vessel of actinic glass, but in each case silver oxide separated and no trace of the silver salt was formed.

p-OXYDIPHENYLPHTHALID.²

from the theory, yield one colorless ester and one colorless salt.

This substance was prepared according to Baeyer's method, by condensing phenol and benzoylbenzoic acid with concen-

¹ Ber. d. chem. Ges., 26, 172.

² Ann. Chem. (Liebig), 354, 162.

trated sulphuric acid and crystallizing the product from glacial acetic acid. It melted at 164° .

Solubility of p -Oxydiphenylphthalid in Alkali.

Amount of acid dissolved.	Calculated cc. of 0.1 N NaOH, one molecular equivalent to one of acid.	cc. NaOH required.
0.1044	3.46	11.34
0.0700	2.32	7.28

That this acid is extremely weak and the salt highly hydrolyzed is shown by the excess of alkali above the calculated required for solution.

The sodium and potassium salts of p -oxydiphenylphthalid are precipitated from a water solution by the addition of an excess of a concentrated solution of sodium or potassium hydroxide but it was found impossible to obtain either of these salts for analysis free from alkali. The attempt to isolate other metallic salts also proved futile.

A colorless oil was formed by heating a solution of the p -oxydiphenylphthalid in absolute alcohol with sodium wire but was not obtained pure. No salt was formed on boiling a solution of the acid in anhydrous ether with sodium wire for five hours.

We experienced the same difficulty in attempting to isolate the alkali salts of benzo- p -cresophthalein.

On methylating p -oxydiphenylphthalid with methyl iodide and alcoholic sodium hydroxide a colorless ester was obtained, but not in pure condition.

DIBROM- p -OXYDIPHENYLPHTHALID.

p -Oxydiphenylphthalid was dissolved in glacial acetic acid, at about 60° , and a solution of bromine in glacial acetic acid was added. On cooling the solution, the dibrom- p -oxydiphenylphthalid separated out. On crystallization from acetic acid this was obtained pure in white crystals which melt at 199° .

The methyl ester prepared with diazomethane gave on analysis the following results:

	Calculated for $C_{21}H_{16}O_3Br_2$.	Found. (Carius method.)
Br.	33.75	I. 33.48 II. 33.24

Dibrom-*p*-oxydiphenylphthalid was methylated by alcoholic sodium hydroxide and methyl iodide. The methyl ester was obtained as a white powder which crystallizes readily from glacial acetic acid and melts at 157° .

By methylating the dibrom-*p*-oxydiphenylphthalid with diazomethane an identical ester was obtained, melting at 157° . No lowering of the melting point was produced on fusing a mixture of these esters.

These experiments seem to prove very clearly that the sodium salt and the free acid have the same constitution, that of the lactoid form, and give evidence that our theory of tautomeric salts is correct.

EXPERIMENTS WITH THE DILATOMETER.

It seemed likely that the affinity constants of these weak acids might be determined by the use of the dilatometer,¹ provided no salt effect interferes. This method depends on the reversible reaction involved in the condensation of acetone, and the splitting of the diacetone alcohol thus formed into two molecules of acetone. The expansion of the solution due to the change of the diacetone is generally measured. This reaction is catalyzed by the presence of hydroxyl ions and the velocity is proportional to the concentration of these ions.

The diacetone alcohol was prepared by extracting pure calcium hydroxide in a Soxhlet extractor with acetone, according to Hofmann's method. The solution was freed from water and acetone by distilling it under diminished pressure and was then fractionated. The solutions measured contained from two to ten per cent of the diacetone alcohol in conductivity water. A solution of diacetone alcohol in conductivity water showed no appreciable change after standing several months. The measurements were made in a constant tem-

¹ Koelichen: Z. physik. Chem., **33**, 132.

perature bath at 25°. The variation during the experiment was only 0°.01.

Velocity constants for sodium hydroxide having a concentration of N/10, N/20, N/40, N/80, and 160 in the N/ dilatometer were obtained from the equation for the reaction of the first order, $\frac{A}{t(A-x)} = K$. The results are given in Tables I.-V., inclusive.

Equal volumes of ten per cent diacetone alcohol and alkali of the proper strength to give the above concentrations were used. In the tables t is the time in minutes, A the total expansion in divisions on the dilatometer stem, and K the velocity constant.

Table I.—0.1 N Sodium Hydroxide. $A = 68.1$.

t .	$A-x$.	K .	t .	$A-x$.	K .
10	40.0	0.0224	30	14.2	0.0224
15	30.8	0.0226	40	8.4	0.0225
20	24.2	0.0221	50	4.8	0.0224
25	18.4	0.0223			

Mean, 0.0224

Table II.—0.05 N Sodium Hydroxide. $A = 36.0$.

t .	$A-x$.	K .	t .	$A-x$.	K .
5	31.3	0.0119	50	9.6	0.0115
15	23.9	0.0116	55	8.5	0.0114
25	18.4	0.0117	85	3.8	0.0114
35	13.9	0.0118			

Mean, 0.0116

Table III.—0.025 N Sodium Hydroxide. $A = 44.2$.

t .	$A-x$.	K .	t .	$A-x$.	K .
30	29.5	0.00585	100	12.0	0.00575
40	25.7	0.00589	120	9.4	0.00572
60	20.0	0.00574	150	6.4	0.00577
80	15.5	0.00571			

Mean, 0.00578

Table IV.—0.0125 N Sodium Hydroxide. $A = 41.2$.

t .	$A-x$.	K .	t .	$A-x$.	K .
10	38.6	0.00273	100	22.6	0.00271
30	34.2	0.00270	130	19.0	0.00269
50	30.2	0.00270	160	16.0	0.00270
70	27.3	0.00270			

Mean, 0.00270

Table V.—0.00625 N Sodium Hydroxide. $A = 48.0$.

t .	$A-x$.	K .	t .	$A-x$.	K .
20	45.5	0.00117	200	29.0	0.00119
50	41.9	0.00118	260	24.8	0.00110
80	38.9	0.00116	320	21.5	0.00119
140	33.5	0.00112			
Mean, 0.00116					

Dilatometer Measurements of Solutions of Phenolphthalein.

—The pure sodium salt of phenolphthalein was prepared by shaking an excess of the acid with alkali a number of hours and carefully filtering out the excess of acid. A portion of the filtrate containing 0.400 gram of the disodium salt was placed in the dilatometer with an equal volume of ten per cent diacetone alcohol. In Tables VI. and VII., A has been calculated only approximately from a number of experiments.

Table VI.— $A = 100$.

t .	$A-x$.	K .	t .	$A-x$.	K .
1480	92.6	0.000022	3280	83.5	0.000023
1900	89.6	0.000022	4150	80.8	0.000022
2620	87.6	0.000023	4900	78.1	0.000021
Mean, 0.000022					

Table VII.— $A = 100$.

t .	$A-x$.	K .	t .	$A-x$.	K .
960	92.9	0.000023	3420	83.6	0.000022
1830	90.2	0.000023	4080	80.6	0.000022
2250	89.4	0.000021	6140	69.2	0.000024
Mean, 0.000022					

This volume for K_{trans} corresponds to a hydroxyl ion concentration of 0.00012 N. If we take as the concentration of the phenolphthalein in saturated solution the value 0.0012 N found by McCoy¹ and remember that the solution of the phenolphthalein salt is diluted with an equal volume of the solution of diacetone alcohol, we should obtain 2×10^{-7} for the hydrolysis constant, or 0.6×10^{-7} for the affinity constant of phenolphthalein. This is much larger than the values ob-

¹ THIS JOURNAL, 31, 511.

tained by Salm, McCoy, Hildebrand, and Wegscheider and shows most decidedly, as do Tables VIII. to XI., inclusive, that the phenolphthalein salt lowers the catalytic effect of the hydroxyl ions very materially. Unless we can find some means to obviate this the method can not be used to determine the affinity constants of these indicators and related compounds.

Solutions of phenolphthalein were then prepared by dissolving a definite amount of the acid in a sodium hydroxide solution containing varying amounts of the alkali. Dilatometer measurements were made with these solutions. The results are given in Tables VIII. to XI., inclusive. It is seen that the velocity constant decreases with increase in the amount of phenolphthalein present.

In the following tables, the amounts of alkali used are expressed in molecular equivalents for one molecular equivalent of acid:

Table VIII.—4.6 N/40 NaOH. $A = 50.5$.

t .	$A-x$.	K .	t .	$A-x$.	K .
10	45.9	0.00424	60	28.2	0.00421
20	41.6	0.00420	80	22.8	0.00421
30	37.8	0.00429	120	15.4	0.00429
40	34.2	0.00423			

Mean, 0.00424

Table IX.—20 N/10 NaOH. $A = 34.2$.

t .	$A-x$.	K .	t .	$A-x$.	K .
8	24.2	0.0187	24	12.1	0.0187
12	20.3	0.0188	28	10.2	0.0187
16	17.1	0.0187	36	7.2	0.0187
20	14.5	0.0186			

Mean, 0.0187

Table X.—40 N/10 NaOH. $A = 28.8$.

t .	$A-x$.	K .	t .	$A-x$.	K .
12	15.9	0.0215	28	7.3	0.0212
15	13.8	0.0213	38	4.5	0.0212
20	10.9	0.0210	49	3.4	0.0210
24	8.9	0.0212			

Mean, 0.0212

Table XI.—70 N/20 NaOH. $A = 34.3$.

t .	$A-x$.	K .	t .	$A-x$.	K .
5	30.0	0.0116	30	15.9	0.0110
10	26.5	0.0112	40	11.5	0.0118
15	23.1	0.0114	50	9.6	0.1009
20	20.6	0.0110			
Mean, 0.0113					

Dilatometer Measurements of Solutions of p-Oxydiphenyl-phthalid.

These solutions were prepared by dissolving the acid in varying amounts of caustic soda. The results of the dilatometer measurements are given in Tables XII. to XIV., inclusive. The same salt catalysis is noticed in this case as with phenolphthalein. This salt catalysis was noticed by Koelichen, who found that some salts acted as negative and others as positive catalyzers.

Table XII.—20 N/10 NaOH. $A = 34.8$.

t .	$A-x$.	K .	t .	$A-x$.	K .
8	28.3	0.0112	40	12.4	0.0111
16	23.2	0.0110	56	8.2	0.0112
24	18.7	0.0112	72	5.3	0.0113
32	15.3	0.0111			
Mean, 0.0112					

Table XIII.—40 N/10 NaOH. $A = 32.3$.

t .	$A-x$.	K .	t .	$A-x$.	K .
5	25.3	0.0212	30	7.7	0.0218
10	19.9	0.0210	40	7.7	0.0218
15	15.5	0.0212	60	2.0	0.0217
20	11.8	0.0218			
Mean, 0.0215					

Table XIV.—80 N/10 NaOH. $A = 33.6$.

t .	$A-x$.	K .	t .	$A-x$.	K .
5	25.8	0.0229	25	9.0	0.0227
10	19.9	0.0227	30	7.0	0.0228
15	15.1	0.0229	40	4.0	0.0229
20	11.7	0.0229			
Mean, 0.0228					

The above results for the various concentrations of sodium hydroxide, phenolphthalein, and *p*-oxydiphenylphthalid are shown in Fig. I., plotted in the form of a curve.

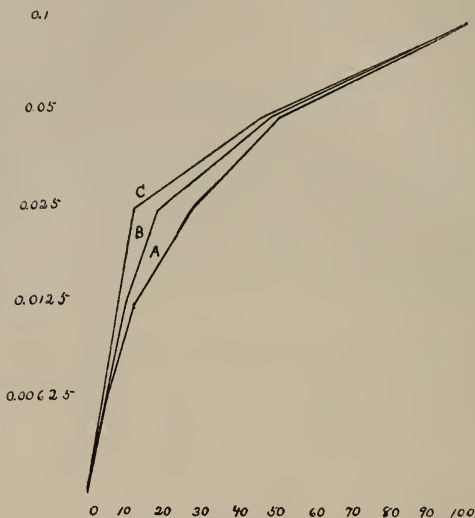


Fig. I.

The abscissas represent the velocity constants, K , and the ordinates the normality of the original alkaline solutions. Curve A shows the results for sodium hydroxide (the deviation of A from a straight line is, of course, due to the suppressed ionization at the higher concentrations); curve B shows the results obtained with the phenolphthalein solutions; and C, those obtained with solutions of *p*-oxydiphenylphthalid. The decrease in the velocity constant due to the presence of the phthalein or phthalid salt is very clearly shown, the decrease being greater in the case of *p*-oxydiphenylphthalid, C, than in the case of phenolphthalein, B.

A New Dilatometer.

It is readily seen that the glass dilatometer as devised by Koelichen is not sufficiently sensitive for studying very dilute solutions of alkali nor for the very accurate investigation of this salt catalysis. An attempt was made to obtain a more sensitive instrument by following the plan used by Prof. Morse in his work on osmotic pressure.

A brass cell (Fig. II.) was made, with a capacity of 25 cc. and an internal diameter of 17 mm., the wall being 2 mm. thick. The cell was uniformly nickel-plated inside and outside. It was closed by a brass cone (*b*) into which was fastened with Wood's metal (*c*) an open manometer tube, etched in 1 mm. divisions, and having a bore of 0.5 mm. diameter. A small platinum tube (*d*) opening within the cell, by the side of the manometer, was also fastened into the cone. This small tube could be closed with a screw cap (*e*).

The cap was used to regulate the height of the liquid in the manometer before the measurements were taken. When a measurement was to be taken the manometer tube was filled with pure water. The diacetone alcohol and alkaline solution were brought to the proper temperature, thoroughly mixed, and then poured into the cell. The cone containing the manometer was then quickly placed in the cell and tightened by the threaded brass collar (*g*). The superfluous liquid was allowed to escape from the small platinum tube until the meniscus was at the proper height in the manometer tube and the screw cap was then tightly closed. It was found impracticable to use washers of any kind between the cone and the cell at (*f*), as their slightest contraction or expansion caused a change in the volume of the cell and hence an error in reading. A watertight connection was obtained at this point (*f*) by the use of a thin layer of a mixture of vaseline and the lubricant obtained by melting together rubber and paraffine.

During the measurements, which lasted from three to nine hours, the instrument was immersed so that the meniscus was at a constant level in a constant temperature bath. The

temperature must be carefully regulated as a change of more than $0^{\circ}.005$ of a degree causes considerable error in reading.

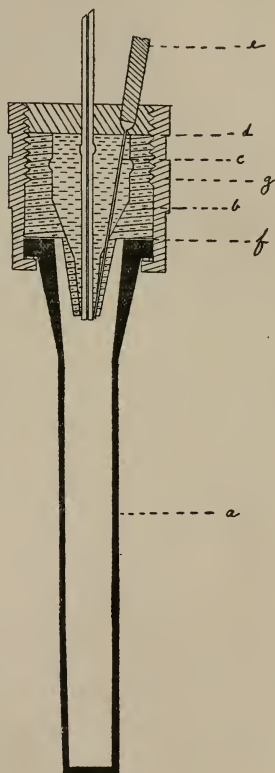


Fig. II.

A number of improvements have suggested themselves while working with this instrument, yet the advantages of the present type over the glass dilatometer are evident. This

cell, when placed in the bath, will attain temperature equilibrium in two to three minutes. The following tables will show the degree of accuracy that can be attained. In these measurements a 2 per cent solution of diacetone alcohol was used.

Table XV.—0.0483 N Sodium Hydroxide. $A = 14.29$.

<i>t.</i>	<i>A</i> — <i>x.</i>	<i>K.</i>	<i>t.</i>	<i>A</i> — <i>x.</i>	<i>K.</i>
2	13.57	0.01123	31	6.41	0.01125
4	12.89	0.01120	41	4.95	0.01120
6	12.23	0.01126	51	3.83	0.01123
21	9.32	0.01121	61	2.95	0.01126
26	7.13	0.01126			
Mean, 0.01123					

Table XVI.—0.0227 N Sodium Hydroxide. $A = 22.90$.

<i>t.</i>	<i>A</i> — <i>x.</i>	<i>K.</i>	<i>t.</i>	<i>A</i> — <i>x.</i>	<i>K.</i>
10	20.10	0.005673	35	14.50	0.005670
15	18.39	0.005677	50	11.92	0.005671
20	17.63	0.005679	60	10.46	0.005672
25	16.52	0.005672	70	9.18	0.005672
30	15.47	0.005678			
Mean, 0.005675					

These are remarkably good constants and serve to show how accurate our chemical methods can be made. Doubtless many other reactions can be studied by such methods and we shall continue the work as outlined above.

EXPERIMENTS ON THE RADIOACTIVITY OF ERBIUM, POTASSIUM, AND RUBIDIUM COMPOUNDS.

BY W. W. STRONG.

The work of Thomson, Campbell, Wood, McClennan, and others has indicated that potassium and probably rubidium are radioactive. McClennan and Kennedy¹ have studied the salts of various metals and find that only potassium salts are appreciably active. Levin and Ruer² find that potassium salts emit radiations that are about a thousandth part as

¹ Phil. Mag., 93, 377 (1908).

² Physik. Z., 8, 248 (1908).

strong as the β rays from uranium. The latter investigators used the photographic method. This method is quite easy and has been used in this work, which is merely a preliminary one. The activity of any of the ordinary elements which has been thus far observed is so small that it could be explained as due to but a minute trace of any of the so-called radioactive elements. No good method has as yet been brought forward to show the absence of any such impurity and the only way we have of settling this important problem is to investigate various kinds of salts of the substance prepared by different methods and from materials derived from as many different sources as possible. For this reason the present work does not prove that erbium, potassium, and rubidium are radioactive, but it indicates that there is considerable evidence that they are.

Several years before his death, Prof. Rowland collected several minerals and salts of the rarer elements, and through the kindness of Prof. Ames these were placed at the writer's disposal. An investigation of the possible radioactivity of these compounds has been made by the photographic method.

The substances examined include salts of potassium, zirconium, caesium, lead, bismuth, yttrium, tungsten, sodium, molybdenum, niobium, rubidium, erbium, tantalum, lanthanum, vanadium, neodymium, praeodmium and ruthenium. Most of the substances were collected by Prof. Rowland about fifteen years ago and may be considered "old" from a radioactive point of view.

The method of investigation consists of exposing "Seed's Dry Plates" for about six months to the salts. The salt is usually placed in a small dish covered with a screen containing several openings. Above this opening is the photographic plate, the film side being next the salt. As most of the salts had been in cork-stoppered bottles for years, there was usually not much danger of chemical action although in several instances this trouble occurred. Intense impressions were obtained from uranyl compounds for exposures of thirty hours or more.

Of the results obtained, only those are given that indicate that the substance is radioactive.

Potassium salts: Potassium cyanide (purchased for photographic purposes) gave a photographic impression on being exposed 150 days. Thin aluminium foil (0.00156 cm. thick) did not cut off much of the radiation from the salt. Thicker aluminium foil (0.006 cm. thick) absorbed about half the radiation. A sample of potassium benzoate (Row. collection) exposed for 150 days, produced a very slight photographic impression. Potassium citrate (Row. col.) exposed 160 days showed a weak photographic action that was not screened off by thin aluminium foil, but was entirely screened off by sheet iron (0.044 cm. thick). Potassium urate (Row. col.) showed practically no effect after an exposure of 150 days. Potassium carbonate (Row. col.) gave a strong impression after an exposure of 160 days. The radiations were absorbed by sheet iron. On the other hand, potassium carbonate recently purchased for photographic work (Mallinckrodt) showed practically no activity at all. The same was true of potassium chromate (Row. col.) which was exposed 150 days. These results seem to indicate that potassium salts, both the "new" and the "old," are radioactive, and that this activity is not much greater than can be detected by this method. Many commercial salts of potassium (especially potassium cyanide)¹ contain but small amounts of potassium, and would therefore be but slightly active and would require much longer exposures than those given above.

Of the lead compounds investigated, only one, lead peroxide, was slightly active. Metallic lead usually gives very marked photographic effects. These do not appear to be due to a β -like radiation, however, for if the lead is placed a short distance from the plate, the effect is much reduced. The effect may be due to a δ -like radiation. Wood gave effects somewhat similar to those of lead.

A sample of erbium chloride gave a very strong impression after an exposure of 110 days. This salt belonged to the Rowland collection. Several years ago the University pur-

¹ McClennan and Kennedy: *Phil. Mag.*, **93**, 386 (1908).

chased some "erbium metal" from the Harrington Brothers, London. This powdered "metal" also gave a very strong impression. The erbium chloride is known, from the spectroscopic observations, to contain a large amount of erbium. The absorption spectra of the powdered "erbium metal" did not show a trace of the erbium spectrum.

A powder marked "Samarkite oxides" (Row. col.) did not show any activity. Samples of samarkite earths and monazite sand (Barker Co., N. C.) showed indications of marked radioactivity.

Rubidium chloride gave a slight impression and rubidium chlorate a very strong impression after exposures of 110 hours.

Not a single one of the other salts showed the slightest indications of being radioactive. The fact that most of the potassium salts and all of the erbium and rubidium compounds tried gave photographic impressions, indicates a probability that potassium, erbium, and rubidium are radioactive.

JOHNS HOPKINS UNIVERSITY,
June, 1909.

PRODUCTION OF CARBON DIOXIDE FROM SOLUTIONS OF COMPOUNDS OF SILICON, ZIRCONIUM, BISMUTH, AND THORIUM.

BY SIR WILLIAM RAMSAY.

In the following extract from Sir William Ramsay's presidential address, delivered before the London Chemical Society on March 25th, 1909, entitled "Elements and Electrons" and published in the *Journal of the Chemical Society* for April, 1909,¹ are described a number of experiments which lead him to believe that he has effected the transmutation of four other elements, besides copper, into an element of lower atomic weight, *viz.*, of silicon, zirconium, bismuth, and thorium into carbon. He says:

No one is better aware than I am how careful one should be in publishing results; but it has appeared to me best to make public the conclusions to which my experiments have led

¹ Vol. 95, pp. 624-637.

me; if the experiments are faulty, they will be repeated and corrected; if just, they will be corroborated.

I need here only allude to the transformation of radium emanation into helium, discovered by Mr. Soddy and myself. The accuracy of this observation has been amply established. Owing to the fact that during this transformation the energy evolved is in the most concentrated form known, and that the emanation of radium is fairly easily soluble in water, and therefore in aqueous solutions, the action of the emanation on a solution of copper sulphate and nitrate was investigated, glass vessels being employed. Four experiments were made, each one in duplicate; the duplicate was in each case treated like the solution containing emanation; the only difference was that the duplicate solutions contained no emanation. From the emanation-solutions, a larger residue was obtained in each case than from the duplicate; and while the residue from the emanation-solutions showed the presence of a trace of lithium, those from the duplicates failed to give spectroscopic evidence of the presence of lithium. The fact of the experiments having thus been carried out in duplicate renders inapplicable the criticism of Professor Hartley, that inasmuch as lithium is a widely distributed element, accidental contamination is probable. But the alleged repetition of the experiments of Madame Curie and Mlle. Gleditsch, in which, using platinum vessels, they obtained no greater residue, and no trace of lithium, cannot be thus explained away. There are two possible replies: either the conditions of experiment varied, so that the same result was not obtained; or it is conceivable that in presence of emanation and a copper solution, a trace of lithium was dissolved from the glass vessel (which had been tested for lithium, however, with negative result), which escaped solution in absence of emanation, on the one hand, or in the absence of copper, on the other. For emanation in presence of distilled water in a vessel of the same glass gave a minute residue in which the spectrum of lithium was not to be observed.

I may be permitted here to mention a research carried out by Mr. Alexander Cameron, under my supervision, on the

action of emanation on a solution of silver nitrate in a silica bulb, no glass, but only silica and platinum vessels, having been used for the experiments. Two experiments were made, in which the silver nitrate solution was left over a month in presence of the emanation from 0.2111 gram of radium, reckoned as metallic. Two similar blank experiments were made, in which no emanation was introduced into the bulb. These experiments had the object of ascertaining whether the "treated" silver nitrate gave a larger residue than the "untreated." The utmost pains were taken, it is needless to say, to avoid the introduction of any solid matter with the reagents employed. The results were negative; they are as follows:

	Residue from "treated" silver nitrate.	Residue from "untreated" silver nitrate.
Expt. 1	0.00022	0.00032
Expt. 2	0.00027	0.00007

The differences are so small, and the difficulty of avoiding contamination so great, that no positive conclusion can be drawn from the experiments. It is really impossible to manipulate quantities of the order of a few tenths of a milligram. The residues showed only the spectrum of sodium.

But the available energy of the radium emanation was certainly largely expended in producing another change, for a large amount of metallic silver was deposited—no less than 0.23 gram. Besides this, the gases evolved consisted of: Oxygen, 1.038 cc.; hydrogen, 0.071 cc.; nitrogen, 0.084 cc.; and carbon dioxide, 0.016 cc.;¹ in all, 1.209 cc.

The total amount of emanation with which these solutions were treated was respectively 0.78 and 0.92 of that evolved from a gram of radium in 3.86 days—a comparatively large dose, and one capable of evolving about 5,000 gram-calories.

It is, however, possible that silver is a very "stable" element, and that a bad selection has been made. Judging again by analogy with compounds, if it were required to separate carbon from one of its compounds, it would puzzle a beginner if carbon dioxide were the particular carbon compound fixed

¹ The carbon dioxide was probably due to the grease of the stopcock of the burette in which the explosion was carried out.

on as a source of carbon; while, with cane sugar, mere application of heat would reveal its content of carbon. Only repeated experiment can solve this problem—to discover the less stable, and, therefore, more easily degraded, elements. Probably they should be sought for among those of high atomic weight.

I have, however, stumbled across a case of apparent transformation, in working in a totally different direction. After the demonstration that helium is a transformation-product of radium, Debierne showed that it is also to be obtained from actinium. Naturally, the idea occurred that thorium should also yield helium. Now, the radioactive constant of thorium is only the $1/180,000$ th part of that of radium; hence the necessity of working with a very much larger quantity, over a very much longer time.

Miss Burke was so good as to purify for me 270 grams of thorium nitrate, $\text{Th}(\text{NO}_3)_4$. On December 20th, 1905, it was dissolved in about 300 cc. of water, and introduced into a round-bottomed flask, provided with a capillary neck, on which was sealed an excellent stopcock. The stopcock was greased, and after the flask had been evacuated with a Töpler pump, the tap was closed. After some hours, it was again pumped empty, and again left; and this proceeding was repeated at intervals, until absolutely no gas could be pumped off. The thorium nitrate was fairly acid, for unless some free acid is present, it is difficult to avoid its being hydrolyzed by water. After this complete withdrawal of all gas, the glass connection to the Töpler was broken; the upper part of the capillary tube, above the stopcock, was filled with water, and the flask was inverted into a jar of water. During the three years in which the gaseous contents of the flask were under observation no trace of leakage at the stopcock occurred; no water entered. Had leakage occurred, it would have been detected by a line of demarcation in the capillary tube, between the strongly refracting solution of thorium nitrate and the less refractive water.

The flask was left for 168 days, and was then sealed to a Töpler pump, with a U-tube, cooled with liquid air, interposed

between the flask and the pump. On opening connection to the pump, a white substance deposited in the U-tube. As the presence of carbon dioxide was not suspected (the experiment having been made to test for helium), this white deposit was not investigated; there was, however, a suspicion that it might be carbon dioxide. The total volume of gas collected measured 3.523 cc.; it contained 0.061 cc. of explosive mixture of hydrogen and oxygen. The residue was mixed with excess of oxygen, and the nitrogen removed by sparking in presence of caustic potash. The gas remaining was then introduced into a tube containing phosphorus, and the oxygen was removed. The minute residue was forced into a minute capillary vacuum-tube, and its spectrum examined. The tube was nearly phosphorescent; I could not be certain, but I suspected that I saw the yellow line of helium. The flask was treated as before, and set aside for 250 days (June 6th, 1906, to February 11th, 1907). The gas then pumped off was analyzed. Its volume was 5.750 cc.; it contained 0.588 cc. of carbon dioxide, absorbable by potash, and 0.017 cc. of hydrogen plus oxygen; the residue, 5.145 cc., was pure nitrogen. Here the volume of gas emitted from the thorium nitrate was nearly proportional to the time. Again, helium was sought for, but without definite result; the yellow line was doubtful.

After closing the flask as before, it was kept for 173 days, until August 3rd, 1907. The gas, on analysis, gave carbon dioxide, 1.08 cc.; hydrogen and oxygen, 0.02 cc.; and nitrogen, 1.64 cc.; the total volume was 2.74 cc. The testing for helium was very satisfactory as regards manipulation, but the presence of the D_2 line was questionable.

On August 14th, 1907, a control experiment was started, in which a solution of 300 grams of mercuric nitrate, in the minimum quantity of water, was enclosed in a similar flask, pumped empty, and inverted. This salt was chosen because mercury is not supposed to be a radioactive metal, and because of the known oxidizing qualities of mercuric nitrate. The gas withdrawn from this flask on March 30th, 1908, consisted of 0.015 cc. of carbon dioxide, 0.034 cc. of oxygen, and 3.628 cc. of nitrogen. That from the bulb with thorium nitrate con-

tained 1.209 cc. of carbon dioxide, 0.016 cc. of hydrogen and oxygen ($H_2 + O_2$), and it left a residue of 1.321 cc. of nitrogen. After sparking down, there was distinct evidence of a helium spectrum; that is, the D_2 line was observed, but the tube almost at once "ran out." To make certain, however, of the production of helium from thorium, a larger quantity is evidently necessary.

The next analysis was made on February 9th, 1909. It occurred to me that although the grease on the stopcock had been exposed to only a trace of liquid—that in the narrow capillary tube—still, carbon dioxide might have been produced in presence of thorium, although the similar experiment with mercuric nitrate gave a practically negative result. To guard against this, a little metallic mercury was introduced, without letting in a trace of air. When the flask was inverted, the capillary tube was filled with mercury, which effectually protected the stopcock from contact with the thorium solution. On examining the flask on February 9th, 310 days after the gas had been withdrawn, no bubbles could be detected between the stopcock and the mercury; had carbon dioxide risen from the grease, it must have been trapped there.

The result of the presence of this mercury was unexpected. Instead of the 3 or 4 cc. of gas, no less than 180 cc. were collected; analysis of a small portion showed that it was almost pure nitrogen. To extract the carbon dioxide, the whole of this gas was liquefied in a bulb cooled with liquid air, under a pressure of two atmospheres; and the nitrogen was allowed to boil away into a gas-holder. The residue in the bulb was collected separately. The process was repeated a second time. The first small portion of gas contained 0.411 cc. of carbon dioxide; the second, 0.103, in all, 0.622 cc. It is probable, however, that not all was then separated, for carbon dioxide has still a small vapor pressure at -185° .

These experiments render it at least probable that thorium nitrate "engenders" carbon dioxide; or, in other words, that one of the degradation products of thorium is carbon.

To test this question further, two quantities of thorium nitrate, carefully purified, were treated with radium-ema-

tion, which had stood for some hours in a tube containing moist potash. It was introduced rapidly into a bulb, and the only chance of contamination with carbon compounds was while it passed through a stopcock on its way to the bulb; the time of contact cannot have been a fraction of a second. A special experiment, to be described elsewhere, has shown that grease, in contact with emanation, yields, when oxygen is absent, nothing but pure hydrogen; not a trace of carbon dioxide.

The first quantity of thorium solution was charged with emanation on June 3rd, 1908; the bulb was opened, and the gas analyzed, on November 18th. Nitric peroxide was present; it was removed by shaking with mercury, some pure oxygen having been added to combine with nitric oxide. The volume of the gas was then 5.579 cc. No electrolytic gas was present, but 0.551 cc. of carbon dioxide, 1.342 cc. of oxygen, and 3.686 cc. of nitrogen. The method of filling this bulb absolutely precluded entry of air at any time. The same solution in the same bulb was recharged with a much smaller quantity of emanation on November 20th; the bulb was opened on February 2nd, 1909. After removal of oxides of nitrogen with mercury as before, the volume was 1.789 cc.; it contained 0.124 cc. of carbon dioxide, 1.026 cc. of oxygen, and 0.639 cc. of nitrogen; there was no electrolytic gas.

From these experiments it would appear that the action of radium emanation on thorium nitrate solutions is also attended with the formation of carbon dioxide. Thorium belongs to the same natural family as carbon; and experiments were next tried with another member of the same family, namely, zirconium. Two bulbs were therefore charged with an acid solution of zirconium nitrate, and each "dosed," on August 19th and 26th, 1908, respectively, with the radium emanation from 0.2111 gram of radium as bromide, gathered during eight days. The gases were analyzed as on the 20th November. After oxides of nitrogen had been removed, the remaining samples had the following composition:

	I.	II.
Carbon dioxide	0.124	0.116
Carbon monoxide	0.002	0.008
Nitrogen	0.456	0.762
Oxygen	3.831	3.665

There was no electrolytic gas.

Having obtained carbon dioxide from zirconium nitrate, hydrosilicofluoric acid was similarly treated with the emanation of a week's gathering from the same quantity of radium. The carbon dioxide from 10.2 cc. of what was practically all electrolytic gas amounted to 0.106 cc. I am much indebted to Mr. Usher for carrying out the analyses of these gases.

To ascertain whether lead, too, yielded carbon dioxide, a bulb was charged with an acid solution of lead chlorate, and dosed with emanation; the bulb was set aside on December 18th, 1908; the gases were extracted and analyzed on January 26th, 1909. The bulb contained a thick deposit of lead peroxide; the gas did not attack mercury, hence there was no free chlorine; it consisted wholly of oxygen, 5.192 cc., and carbon dioxide, 0.007 cc. The amount of the latter gas is here insignificant; and the experiment may be regarded as a blank one as regards the production of carbon dioxide.

A similar experiment was made with bismuth perchlorate, obtained by dissolving bismuth oxychloride in excess of perchloric acid, and evaporating until the solution became syrupy, and until white fumes appeared. Some crystals deposited on cooling. The oxychloride was tested for nitrates and nitrites with brucine; none were present. The pressure in the bulb, on opening, was very high, due to formation of oxygen and chlorine. The total amount of carbon dioxide found was 0.150 cc., and of oxygen about 48 cc. Now, as the solution of bismuth perchlorate had been evaporated until the fumes of perchloric acid were evolved, and as all carbon compounds—dust, etc.—must certainly have been oxidized, the formation of carbon dioxide appears certain. The mercury which had absorbed the chlorine was carefully tested for nitrates, but with negative result; and no nitrogen was present in the gases produced. This may appear curious,

for bismuth belongs to the nitrogen group; but in such matters it would be bold to predict. The fact that nitrogen was absent from the bulbs containing lead and bismuth points to the absence of air, and inferentially also to its absence in the other experiments described. Indeed, it is certain that in all these experiments, all gas was initially extracted from the solutions; and no gas entered during the subsequent manipulations.

Much more might have been said regarding the special precautions taken, For example, a pump with a specially narrow fall-tube was employed; 1 cm. of its length contained about 1 cubic millimeter. The exhaustion of the bulbs was carried so far that no appreciable bubble passed down the fall-tube; 1/100th cubic millimeter could have easily been detected. Again, all vessels were washed out with hydrogen made by heating palladium-hydrogen in connection with a pump; tubes, explosion-burette, measuring-burette, etc., so as to avoid all possible source of contamination. In short, every precaution which could be thought of was taken to exclude all foreign gases. The emanation, besides, before it was introduced into the bulbs, had stood for several hours over moist potassium hydroxide; that treatment had been found repeatedly to exclude all traces of carbon dioxide, for it has been tested for spectroscopically and its absence conclusively proved.

Such are the facts. No one is better aware than I how insufficient the proof is. Many other experiments must be made before it can confidently be asserted that certain elements, when exposed to "concentrated energy," undergo degradation into carbon.

REPORT.

*Relation between Crystalline Form and Chemical Constitution.*¹

The relation between crystalline form and chemical constitution is a subject which has long attracted the attention of

¹ Abstract of an article by William Barlow and W. J. Pope published in *J. Chem. Soc.*, 91, 1150 (1907).

students of chemistry and crystallography. Messrs. Barlow and Pope published an article upon this problem in the *Journal of the Chemical Society*, in 1906, presenting views of fundamental importance which, if supported, lead to far-reaching conclusions. The same authors have since published two articles in which they give many additional facts bearing upon the ideas formerly advanced. Because of the importance of the subject and the significance of their views, it is our purpose to present the chief conclusions reached by the authors in their second article. A review of their last article will appear in a later number of THIS JOURNAL.

In their earlier work, the authors reached two fundamental conclusions, as follows: If each atom be viewed as appropriating a certain space, termed its sphere of atomic influence,¹ then (1) the spheres of atomic influence are so arranged as to occupy the least possible space in every crystal, *i. e.*, they are close-packed; (2) the volumes of the spheres of atomic influence in any body are proportional to the valence of the combining atoms.

A third proposition is now advanced by the authors in addition to the preceding.

(3) In any compound, the volumes of the spheres of atomic influences of atoms of the same valence may differ slightly. In other words, the volumes of equivalent atoms, though approximately the same, may not be absolutely identical.

The latter proposition receives especial consideration in the paper before us.

Method of Investigation.—If the spheres of influence of atoms of the same valence possess the same volume and if the atoms are close-packed in any crystal, as affirmed by the laws previously advanced, it is manifest that crystals formed by combinations of such atoms must possess the properties of close-packed assemblages of equal spheres. The method of the authors, therefore, is to consider first the properties of an ideal assemblage, and then to observe how far the crystal forms assumed by combinations of equivalent atoms accord with those of the ideal assemblage.

The authors consider (I) the ideal assemblages of spheres of equal volume, (II) the crystal form of the various elements,

¹ The authors use the phrase "sphere of atomic influence" to express the space appropriated by the atom, in which respect it is essentially the same as "atomic volume." There appears, however, to be this difference between the terms: the atomic volumes, as commonly determined, express the relative volumes of atoms of the same substance, uniting to form the elementary bodies, while the spheres of atomic influence express the relative volumes of atoms of different elements uniting to form compounds, *e. g.*, the relative volumes of the Na and Cl atoms in NaCl.

and (III) the crystal forms of combinations of equivalent atoms.

I. THE IDEAL ASSEMBLAGES OF CLOSEST-PACKED SPHERES OF EQUAL VOLUME.

Methods of Close-packing.—Two types of closest-packed spheres of equal volume exist, and two only, which may be termed the cubic and hexagonal close-packing, respectively. This may be shown in the following manner: Let the spheres be arranged in contact in one row, as shown in the dotted circles of Fig. I. Let the successive rows be assembled by placing spheres

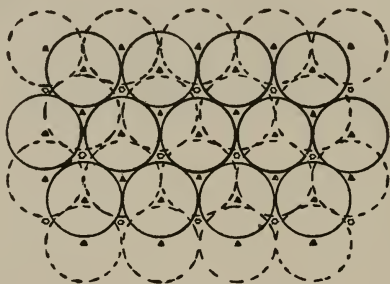


Fig. I.—Projection of hexagonal close-packing seen upon basal pinacoid (0001).

so that they occupy the hollows of the adjoining rows, as shown. The resulting arrangement is the closest-packed assemblage of equal spheres in one plane. Superpose the spheres of a second plane so that they lie in the hollows between those of the first plane, as shown by the solid circles in Fig. I. This gives the closest packing in two planes. The spheres of a third layer may now be superposed in the hollows of the second layer in two different positions:

(1) So that the spheres of the third layer lie immediately over those of the first layer, their centers being in the positions indicated by the small triangular signs in Fig. I.

(2) So that the spheres lie in the intervening hollows indicated by the small hollow hexagons in Fig. I.

These two methods differ in this, that in the first case the spheres of the third layer lie immediately over the spheres of the first layer, while in the second case the spheres of the fourth layer lie immediately over those of the first layer. These are manifestly the only possible ways of closely packing

equal spheres. The resulting structures are illustrated in Figs. I. and VI. and are termed the hexagonal and cubic methods of close-packing, respectively.

One of these arrangements can readily pass into the other by a slight shear in the structure. Thus if the fourth layer of the cubic type slips so as to be over the second layer it will yield the hexagonal arrangement, and *vice versa*.

We will next examine the characteristics of these two assemblages.

Cubic Assemblage of Closest-packed Spheres.

Arrangement of Spheres.—The cubic assemblage of closest-packed spheres may, for the purpose of discussion, be subdivided into cubic cells in which the spheres are close-packed. Of course, such a conception is purely artificial and for the purpose of visualizing the results. There is no such subdivision into cells in nature. Such a cubic cell is outlined in Fig. II. where the observer looks down upon the solid angle of the cube. It is shown, separated from the remaining spheres, in Fig. III. and is viewed from the side in Fig. IV. The cubic cell illustrated contains 5 spheres in each face and may be considered as made of superposed layers of four and five spheres as shown in Fig. IX. A larger cube is illustrated in Fig. V.

The cubic assemblage may also be viewed as made of still smaller units, termed tetrahedra, each tetrahedral group consisting of four spheres occupying the solid angles of a tetrahedron. Their position is shown in Fig. V., in which the spheres of each tetrahedron are inscribed in a small cube. It is important to note that all the tetrahedra have the same orientation, their three-fold axes coinciding with the three-fold axes of the larger cubic cell.

The arrangement of the spheres is shown in greater detail in Figs. VI., VII., and VIII. In these figures, the dotted lines represent the lowest layer, the lighter circles the intermediate layer, and the heavy circles the uppermost layer. Fig. VI. shows the arrangement as seen on the face of the octahedron, Fig. VII. as seen upon the cubic face, Fig. VIII. as seen upon the face of the rhombic dodecahedron.

Symmetry.—Examination of the cubic assemblage shows the following elements of symmetry:

1. Axes of Symmetry.

a. Four-fold axes of symmetry pass through the center of each sphere, normal to the cubic face (Figs. VII. and IX.).

b. Three-fold axes of symmetry pass through the center of each sphere, normal to the octrahedral face (Figs. II and VI.).

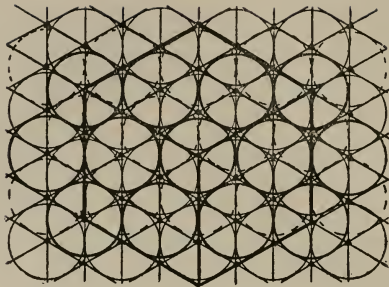


Fig. II.—Cubic close packing projected upon octahedral face (111), showing planes of symmetry. A cubic cell is outlined in center, being viewed looking down upon its solid angle which is in center of diagram. The dotted circles represent lower, the light circles intermediate, and heavy circles upper layer of spheres.

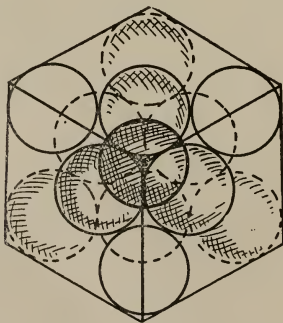


Fig. III.—Cubic cell, looking down upon solid angle.

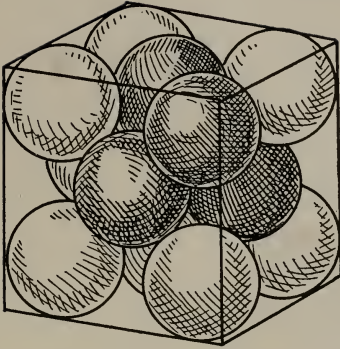


Fig. IV.—Cubic cell seen from side. Four spheres forming a tetrahedron are shaded more heavily.

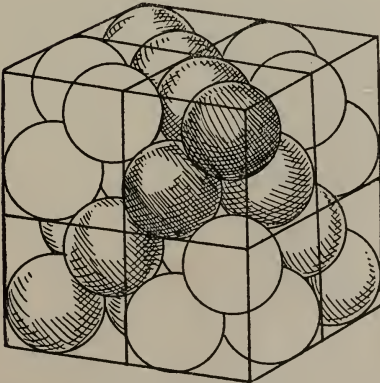


Fig. V.—Cubic cell seen from side. Small cells each occupied by four spheres which form tetrahedra.

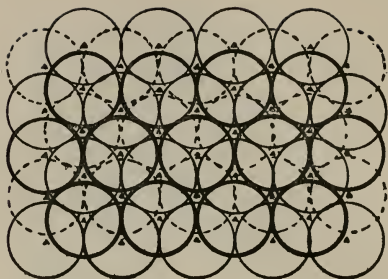


Fig. VI.—Projection of cubic close-packing seen upon the octahedral face (111). The dotted circles lie beneath, the light circles, are intermediate the heavy circles above.

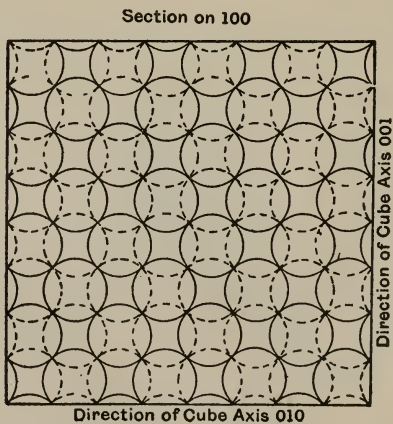


Fig. VII.—Cubic packing. Projection of spheres upon cube face (100).

c. Two-fold axes of symmetry pass through the centers of the spheres, normal to the rhombic dodecahedral face (Fig. VIII.).

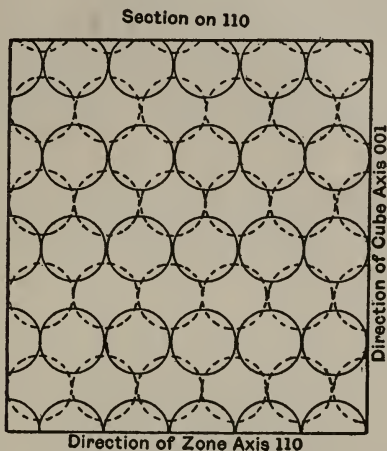


Fig. VIII.—Cubic packing. Projection of spheres upon face of the rhombic dodecahedron (110).

2. *Planes of Symmetry* pass through all the axes (Fig. II.).

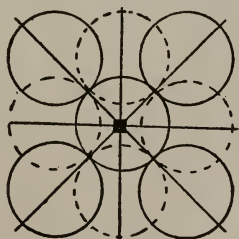


Fig. IX.—Symmetry of cubic packing seen on cube face (100).

The symmetry is well seen in the cubic cell, Fig. IV., as well as Fig. IX., where the four-fold symmetry of the cubic face is shown.

The resulting symmetry is that of the Normal (Holoheral) Group of the Isometric System, in which form, therefore, assemblages of this type should crystallize.

The spheres of atomic influence are viewed as deformable, though incompressible. In close packing so as to eliminate interstitial space, they become polyhedra, the number of whose faces equals the number of spheres with which they are in contact. In the cubic closest-packed assemblage each is in contact with twelve other spheres and hence becomes a rhombic dodecahedron, as seen in Fig. X.

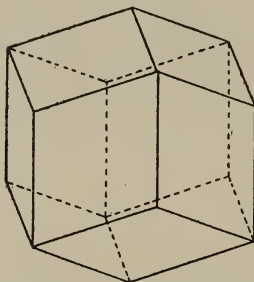


Fig. X.—Rhombic dodecahedron illustrating the shape assumed by the atomic sphere of influence in the cubic close packing.

Hexagonal Assemblage of Closest-packed Spheres.

Arrangement of Spheres.—In the hexagonal type of closest-packed spheres, illustrated in Fig. I., the third layer repeats the first. This assemblage may be viewed, for the purpose of visualizing it, as made of spheres which are close packed in hexagonal prisms. One of these prisms is outlined in Fig. XI., and shown separately in Fig. XII. and in perspective in Fig. XIII., where it is observed from the side marked *p*, *p'* in Fig. XII. It will be observed that certain of the spheres of the intermediate layer project beyond the limit of the cell and fit into corresponding cavities of adjoining cells.

This structure, like the preceding, may be viewed as made of tetrahedra, each of which consists of four spheres. The spheres of alternate tetrahedra are shaded in Fig. XI. A double layer of spheres may be considered as made of alternately inverted tetrahedra. In Fig. XI. the shaded tetrahedra have their apices directed upward, while the bases of the unshaded tetrahedra are directed upward.

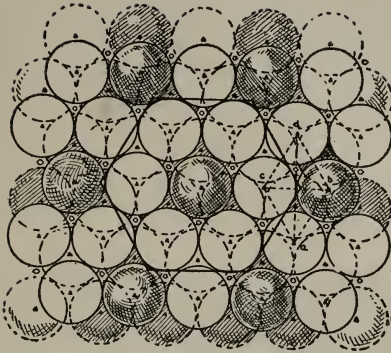


Fig. XI

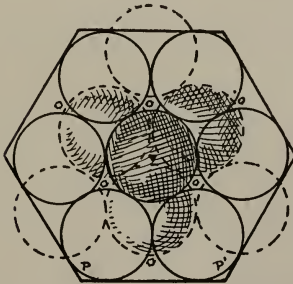


Fig. XII.—Projection of hexagonal cell upon basal pinacoid (0001).

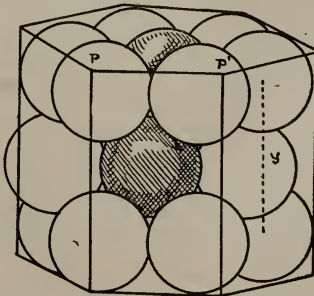


Fig. XIII.—Hexagonal cell seen in elevation. y = translation giving value of c axis.

Symmetry.—The hexagonal close-packed assemblage possesses the following elements of symmetry:

1. *Planes of Symmetry.*—Six sets of planes of symmetry occur normal to the basal pinacoid (0001), 3 sets being ordinary planes of symmetry (heavier lines, Fig. XIV.), and 3 sets are gliding planes of symmetry (lighter lines, Fig. XIV.). Added planes of symmetry pass parallel to the basal pinacoid, as seen in Fig. XIII.

2. *Axes of Symmetry.*—Six-fold screw axes lie in the openings between the spheres, at the intersection of the 6 planes of symmetry (Fig. XIV.). Three-fold axes of symmetry

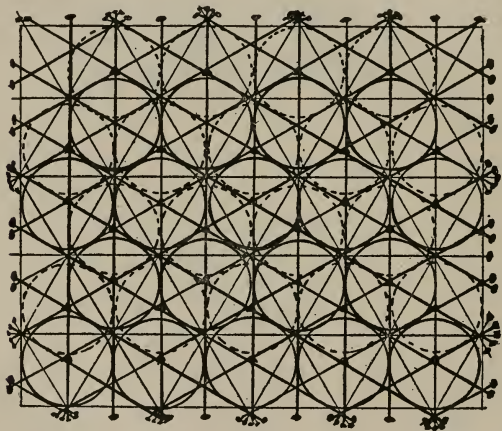


Fig. XIV.—Symmetry of hexagonal packing projected upon basal pinacoid (0001).

pass through the center of each sphere, being produced by the intersection of three planes of symmetry (Fig. XIV.). Horizontal two-fold axes of symmetry are formed at the intersection of the vertical and horizontal planes of symmetry (Fig. XIV.).

The resulting symmetry is that characteristic of the Normal (Holoedral) Group of the Hexagonal System in which group substances of this type should, therefore, crystallize.

Axial Ratio.—The axial ratio may be determined as follows: If the distances between like points in the structure are termed the translation distances (or more simply the translations),

then, according to the Raumgitter theory, the axial ratios are the ratios of the translations distances. It is therefore simply necessary to determine the translation distances. Thus, in Fig. XI., the horizontal translation a is cb which is equal to ab or ad , while the vertical translation c is y (Fig. XIII.). Their relative values are illustrated in Fig. XV.

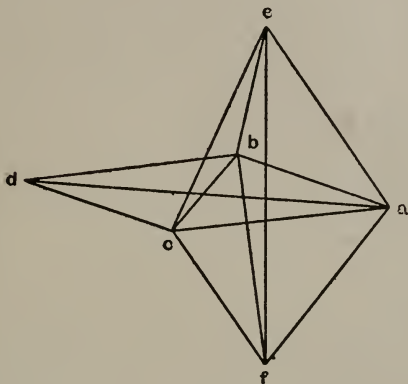


Fig. XV.—Axial ratios of hexagonal close-packed assemblage.

These quantities are easily determined as follows: Let the diameter of the spheres equal 1. Then in Fig. XI., abc is an equilateral triangle in which $bc = 1$ and $ad = \sqrt{3}$. y is twice the altitude of a tetrahedron whose side is 1 (see Figs. XI. and XIII.), hence, $y = 2\sqrt{\frac{2}{3}}$. Two alternative ratios may be used:

(1) The a axis may be chosen in the direction cb , whence $a = 1$ and $c = y = 2\sqrt{\frac{2}{3}} = 1.6330$, and
 $c : a = 1.6330 : 1$.

One-half of the above ratio may be used, giving

$$c : a = 0.8165 : 1.$$

(2) The a axis may be chosen in the direction ad . The a and c directions intersect, as seen in Fig. XV., at one-third

the length of ad . We therefore use $a = \frac{1}{3} ad = \frac{1}{3} \sqrt{3}$,

and $c = \frac{1}{2} y = \sqrt{\frac{2}{3}}$, whence

$$c:a = 1.4142:1.$$

Modifications of the Ideal Assemblages.

The ideal assemblages, above discussed, are produced by the closest packing of spheres of identical volumes. The actual assemblages are believed, in many cases, to depart from the ideal forms in that the spheres of influence of atoms of the same valence, though approximating equality, may not have absolutely the same volume. The actual assemblages, though approaching the ideal, may, therefore, differ from the ideal in possessing a lower grade of symmetry, and in manifesting a slight departure from the ideal axial ratios. It is believed by the authors, however, that equivalent atoms closely approximate equivalency of volume, so that the departures from the ideal forms should, in general, be slight.

If the views of the authors are correct, therefore, all assemblages of equivalent atoms should crystallize in the Isometric or Hexagonal Systems (or in slight modifications of forms belonging to these systems), and should possess axial ratios which closely approximate those of the ideal assemblages. By comparing the actual with the ideal forms, it should be possible to make a somewhat rigid test of the correctness of their theories. This they proceed to do, discussing first the crystal forms of the elementary bodies and secondly the forms produced by combinations of atoms of the same valence.

CRYSTAL FORMS OF THE ELEMENTS.

The spheres of influence of atoms of the same element would be expected to have the same volume. The elements appear, therefore, to be particularly well adapted to test the validity of the authors' conclusions.

The crystal forms of 40 elements are well known and are summarized in the following table.

Crystal Forms of the Elements.

				Per cent.
Crystallizing in the	Isometric	System		50
" " "	Hexagonal	"		35
" " "	Tetragonal	"		5
" " "	Orthorhombic	"		5
" " "	Monoclinic	"		5
" " "	Triclinic	"		0

An examination of the above table shows that 50 per cent of the elements crystallize in the Isometric System, though not all of them occur in the Holohedral Group of the ideal forms, some possessing a lower symmetry, *e. g.*, diamond, which is tetrahedral. The axial ratios of the isometric forms necessarily coincide with the ideal values.

Thirty-five per cent of the elements are hexagonal, most, though not all, being holohedral. The axial ratios approach the ideal values closely, although in most cases they are not absolutely identical with them.

Axial Ratios of Hexagonal Elements.

	Observed.	Ideal.
Glucinum	$a:c = 1:1.5802$	$= 1:1.6330$
Magnesium	$a:c = 1:1.6242$	$= 1:1.6330$
Zinc	$a:c = 1:1.3564$	$= 1:1.4142$
Cadmium	$a:c = 1:1.3350$	$= 1:1.4142$
Arsenic	$a:c = 1:1.4025$	$= 1:1.4142$
Antimony	$a:c = 1:1.3236$	$= 1:1.4142$
Bismuth	$a:c = 1:1.3035$	$= 1:1.4142$
Tellurium	$a:c = 1:1.3298$	$= 1:1.4142$

An examination of the above table shows that 85 per cent of the elements closely approach the ideal forms. Two reasons are suggested for the slight deviations of the observed from the ideal forms. First, imperfection of measurement. Arsenic and magnesium have been measured more carefully than any other of the hexagonal elements and are found to approach most closely to the ideal values. Not all the differences can be accounted for in this manner, however. The authors accordingly suggest that the slight deviations of the observed from the ideal axial ratios, as well as the lowering of the grade of symmetry, are due to slight differences in the volumes of the spheres of atomic influence of atoms of the same element. They show that a slight expansion of every fourth sphere will give the ratios observed in the hexagonal elements.

Iodine, tin, sulphur, and selenium crystallize in other systems, though all closely approach isometric or hexagonal forms. Iodine is orthorhombic with $a:b:c$ almost precisely 2:3:4, an isometric ratio. Tin crystallizes both in the Tetragonal and Orthorhombic Systems. If one-half of the spheres were to become slightly smaller than the others in the ideal cubic assemblage, the forms observed would result. Sulphur possesses four crystal forms, one orthorhombic, two mono-

clinic, and one trigonal. It is shown that the dimensions observed would result if one-third of the spheres were somewhat smaller than the others, the different forms being due to slight differences of arrangement. The crystal form of selenium, which is monoclinic, is explained in a similar manner.

The application of the authors' theories to the crystal form of the elements offers the most direct test of the validity of their views. It is seen that there is a striking general conformity between prediction and observation, associated with certain persistent differences. While eighty-five per cent crystallize in the predicted systems, there is, in some cases, a lowering of the grade of symmetry from the holohedral to less symmetrical groups. The axial ratios are necessarily precise in the Isometric System, but in the Hexagonal System they manifest departures from the ideal values which, though slight, are, at least in a number of cases, too great to be explained as errors of observation. Certain of the elements depart still more widely from the predicted form. It becomes necessary, therefore, to admit that, if the authors' views are correct, the volumes of the spheres of atomic influence of the same elements vary within narrow limits. The authors believe this to be the case, attributing it to some form of preferential treatment of certain of the spheres. The cause of such preferential treatment in a homogeneous structure is, however, not apparent. It remains to be seen how acceptable their idea will prove in the future. With these qualifications, the conformity of the observations with the theory is impressive.

COMBINATIONS OF EQUIVALENT ATOMS.

If the volume is proportional to valence, it is manifest that combinations of atoms of the same valence should crystallize in the Hexagonal or Isometric Systems or exhibit some slight modification of these systems, and should possess axial ratios which closely approximate those of the ideal assemblages. Since there are large numbers of such bodies, it should be possible to submit the authors' views to an extended test. In order to do so they discuss first the binary compounds, and then compounds of more complex character.

1. *Binary Compounds.*

The following table shows the crystal forms of 67 binary compounds examined by the authors.

Crystal Forms of Binary Compounds.

				Per cent.
Crystallizing in the	Isometric	System		68.5
"	"	Hexagonal	"	19.5
"	"	Tetragonal	"	4.5
"	"	Orthorhombic	"	3.0
"	"	Monoclinic	"	4.5
"	"	Triclinic	"	0.0

From the above table it is seen that 88 per cent of the forms studied crystallize either in the Isometric or the Hexagonal Systems. Seven forms do not crystallize in the Isometric or Hexagonal Systems, *viz.*, Hg_2Cl_2 , Hg_2I_2 , FeAs , AsS , AgF , PbO , HgO , CuO . Of these, however, two are compounds of atoms not strictly of the same valence, while mercury and copper present certain anomalies of valency. The volume of the fluorine atom also will be shown to depart considerably from the normal volume of a univalent element. The conformity of the observed and predicted systems is, therefore, very close.

When we examine the crystal group of the bodies, we find that most do not crystallize in the Holohedral Groups of the ideal assemblages. This feature is believed by the authors to be due to slight inequalities in the volumes of the atoms of the different elements, and conforms to the third law.

The relation of the observed to the ideal axial ratio is illustrated by the following five compounds which crystallize in the Hexagonal System and which have been well studied.

Axial Ratios of Hexagonal Binary Compounds.

	Observed.	- Ideal.
GIO	$a:c = 1:1.6305$	$1:1.6330$
ZnO	$a:c = 1:1.6077$	$1:1.6330$
ZnS	$a:c = 1:1.8175$	$1:1.8165$
CdS	$a:c = 1:1.8109$	$1:1.8165$
AgI	$a:c = 1:1.8196$	$1:1.8165$

An examination of the above axial ratios shows that they closely approach the ratios of the ideal compounds though they are not absolutely identical with them.

The authors make elaborate studies of silver iodide and the alkali halogen compounds to see how far both their dimensions and their physical properties may be explained by the assumptions made.

Silver Iodide.

This salt is dimorphous, crystallizing in the Isometric and Hexagonal Systems. The isometric form appears to be holohedral, the hexagonal form is hemimorphic. The axial ratio of the hexagonal modification is $a:c = 1:8196$ (the ideal value = $1:8165$).

Structure.—It was shown in a preceding paragraph that the isometric assemblage may be regarded as made of tetrahedra possessing like orientation, as illustrated in Fig. V. If alternate tetrahedra are replaced by silver spheres while the remaining tetrahedra consist of iodine spheres, an assemblage is produced which represents the cubic modification of silver iodide, according to the views of the authors. This is illustrated in Fig. V., the shaded tetrahedra representing the silver spheres and the unshaded the iodine spheres. In a similar manner they may be combined to produce the hexagonal modification illustrated in Fig. XI.

Symmetry.—The isometric assemblage possesses the holohedral symmetry observed in crystals of silver iodide. In the hexagonal structure, shown in Fig. XI., the tetrahedra of one kind have their apices directed upwards (the shaded tetrahedra) while those of the other kind have their bases directed upwards. This structure possesses vertical but no horizontal planes of symmetry and should therefore be hemimorphic. The observed crystals of the hexagonal modification of silver iodide are hemimorphic. The very slight departure from the ideal axial ratio would be explained by a very slight difference in the volumes of the silver and iodine spheres. The crystal forms may hence be predicted from the structure.

Physical Properties.—The crystals of silver iodide possess unusual properties. The hexagonal variety exhibits a negative coefficient of expansion parallel to the c axis and a small positive coefficient in directions at right angles to it. Upon heating to 145° – 147° it undergoes a transformation into the cubic modification with explosive energy and maintains this form at higher temperatures.

These properties may be explained as follows. It has been shown that silver expands more rapidly than iodine for equal increments of temperature. If this property is manifested by the atoms, and the silver atoms are very slightly smaller than the iodine atoms at low temperatures, then, with increasing temperature they would approach equality of volume. As they approach this condition the structure will become more close-packed, *i. e.*, it will manifest the negative coefficient

of expansion observed in the *c* direction. It would, however, expand slightly in a direction normal to it, since the atoms are in contact in that plane, as seen in Fig. I. When the atoms become equal in volume a slight shear would suffice to transform the whole assemblage to the cubic modification. Upon further heating it would manifest a positive coefficient of expansion, since the structure is becoming less ideally close-packed. If the volumes of the iodine and silver atoms become equal at 145° – 147° we can understand the transformation at that temperature. Both the crystal form and physical properties of silver iodide would therefore result from the structure given.

ALKALI HALIDES.

The authors discuss at some length the various members of the group comprising the chlorides, bromides, and iodides of potassium, caesium, and sodium and related elements, all of which crystallize in the Isometric System and probably in the gyrohedral division of Groth (plagihedral, Dana) which is characterized by possessing many axes but no planes of symmetry.

Structure.—It is suggested that the structure is fundamentally the same as in silver iodide, the metals replacing tetrahedra alternating with those formed by the halogen atoms, as in Fig. V. If the atoms of the metal differ slightly in volume from those of the halogen, the differences being greater than in the case of silver and iodine, the resultant structure would not be close-packed. In order to produce close packing a slight distortion of the tetrahedra is necessary whereby they are transformed into triangular pyramids which slip slightly upon each other in the final adjustment. The result is a structure which is shown to have no planes of symmetry, but which retains its axes of symmetry. In other words, the structure possesses the symmetry of the Gyrohedral Group of the Isometric System in which these salts are observed to crystallize.

Physical Properties.—Most of the crystals of this family possess the following properties: (1) octahedral twinning; (2) elongation in the direction of the three-fold or four-fold axis of symmetry when the salts crystallize from impure solutions; (3) cubic cleavage; (4) gliding in the rhombic dodecahedral face, the translation direction being parallel either to the shorter or longer diagonal of the face. The explanation of these numerous properties presents a difficult test of the theory proposed. All are shown to spring, however, from the fundamental assumptions contained in the theory.

Since the three-fold axes of the crystal are differently terminated at their two extremities, as shown in Fig. V., it is possible to select a given plane of spheres normal to the axes and to build up the structure in a precisely similar manner in two directions from the plane. In this manner the plane becomes a plane of symmetry, *i. e.*, a twin results, the twinning plane being the octahedral face.

Elongation is shown to arise by methods of twinning about the three-fold or four-fold axis in which no new faces are developed, while the phenomena of gliding and cleavage are likewise shown to result from the structures assigned. Thus both crystal form and crystallographic properties are explained by the principles employed.

MORE COMPLEX BODIES.

Among the most interesting bodies discussed are the trihalogen derivatives of the type of CsI_3 , of which a large number are considered. All of these are orthorhombic save KCl_2I , which is monoclinic, and CsCl_2I , which is dimorphous. The structure assigned is built of layers one of which is illustrated in Fig. XVI., the heavy circles representing the metallic base. They are superposed in the hexagonal close packing, as shown

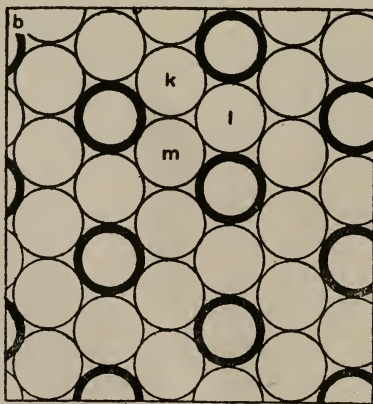


Fig. XVI.—Projection of a single layer of spheres of CsI_3 . The heavy circles represent the Cs spheres.

in Fig. XVII. The symmetry would be trigonal were the atoms of equal volume. It becomes orthorhombic, as observed in the crystals, if the atoms of the different elements differ in volume, while it is shown that slight modifications may give rise to the two exceptional forms. If the axial ratio is written upon three axes then, in the ideal case in which the atomic spheres have equal volumes, $a : b : c = 0.6124 : 1 : 1.0608$, whence the ideal equivalence parameters¹ are $x : y : z = 1.1224 : 1.8329 : 1.9443$.

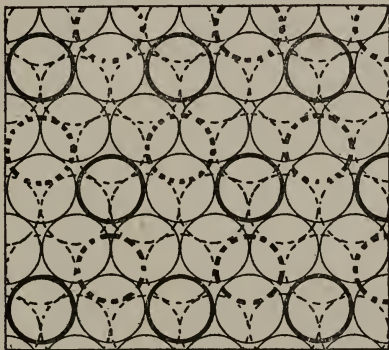


Fig. XVII.—Projection of CsI₃ upon the basal pinacoid (0001) in hexagonal close packing.

In most of the bodies, the observed ratios differ from those of the ideal assemblage. These differences lead to important deductions concerning the relative volumes of the spheres of influence of different elements.

The Principle Involved.—In Fig. XVII. the spheres are in contact in the horizontal line. If now the darker spheres (representing the metal) increase in size, the structure expands horizontally; in other words, the value of x increases, *i. e.*, x is a minimum in the ideal case. As the volumes of the metallic spheres increase the structure will contract in a direction normal to x , since the hollows between adjacent lines of spheres become deeper, permitting them to approach nearer together. Hence y is a maximum in the ideal values. In other words,

¹ See abstract of preceding paper of Barlow and Pope (THIS JOURNAL, 38, 642) for a discussion of equivalence parameters.

an increase in the volume of the spheres of atomic influence of the base, as compared to those of the halogen, will result in a difference between the observed and the ideal values, whereby x increases and y diminishes, the amount of the deviation indicating the relative difference in the volumes of the constituent spheres of atomic influence. The following table shows such differences and permits a calculation of the differences of volume which would account for the deviations observed.

	x .	y .	z .
RbCl ₂ Br	1.2135	1.6982	1.9410
CsCl ₂ Br	1.2250	1.7047	1.9155
RbBr ₂ Cl	1.2060	1.7180	1.9360
RbCl ₂ I	1.2169	1.6576	1.9830
CsCl ₂ I	1.2219	1.6572	1.9754
RbClBrI	1.2166	1.6733	1.9651
CsClBrI	1.2114	1.6756	1.9705
RbBr ₃	1.2017	1.7286	1.9255
CsBr ₃	1.2132	1.7652	1.8678
KBr ₂ I	1.2058	1.6845	1.9694
RbBr ₂ I	1.2044	1.6892	1.9662
CsBr ₂ I	1.2116	1.6821	1.9826
CsBrI ₂	1.1877	1.7173	1.9610
RbI ₃	1.1875	1.7316	1.9452
CsI ₃	1.1901	1.7440	1.9273
KI ₃	1.1846	1.7350	1.9461
Ideal	1.1224	1.8329	1.9443

An examination of the preceding table shows that x is always larger and that y is always smaller in the observed than in the ideal case, in agreement with the above deduction. This indicates that the spheres of influence of the metallic atoms are larger than those of the halogens combined with them. Again, the differences produced by the substitutions of the halogens are less than those produced by the substitution of the metals, indicating that the halogens differ less among themselves than they do from the metals. A comparison of the results produced by the substitution of the halogens in compounds of the same metal, as illustrated by the case of the rubidium salts, shows that the iodine sphere of influence is the largest, that of bromine is intermediate, while that of chlorine is smaller. An examination of the fluorine compounds shows that the sphere of influence of the fluorine atom is still smaller. These results harmonize with the position of these elements in the Periodic System. In a similar manner it is shown

that, of the three bases, potassium, rubidium, and caesium, the sphere of influence of potassium is smallest, that of rubidium intermediate, and that of caesium largest.

These observations lead to the *fundamental conclusion that the volumes of the spheres of influence of the atoms of different elements of the same valency are approximately equal, while they may differ by slight amounts in harmony with their relations in the Periodic System.*

In addition to those discussed in the foregoing outline, many other compounds of equivalent elements are examined. While the results are not so conclusive in all cases, they nevertheless harmonize well with the fundamental conceptions of the authors.

The communication summarized in the above abstract is a notable contribution to the theories concerning the relation between crystalline form and chemical constitution, and is a fundamental addition to the previous discussion of the authors. The wealth of the data reviewed, the far-reaching deductions drawn, and the simplicity of the principles advanced render it worthy of high esteem. The general harmony of theory and observation is very suggestive, while the large number of crystallographic facts for which an explanation is here offered is impressive. There are, on the other hand, certain elements of artificiality in the methods of arriving at the resultant structures which need to be overcome. Further investigation of the differences in the volumes of the atoms of the equivalent elements may remove this difficulty. In the meanwhile, a working hypothesis of much value is offered for the further investigation of the problem of the relation of crystalline form and chemical composition.

CHARLES K. SWARTZ.

REVIEWS.

EXERCISES IN PRACTICAL PHYSIOLOGICAL CHEMISTRY. By SIDNEY W. COLE, M.A. Cambridge: W. Heffer and Sons; London: Simkin, Marshall and Co. Price, 5 shillings.

In writing this little book the author has evidently been actuated by a desire to place before medical students a group of experiments which will yield the greatest amount of information for the least expenditure of time, and described in such a manner that a failure to bring about the desired conclusion shall be attributable only to carelessness or accident. The ground covered and the arrangement are so nearly coincident with those of the conventional laboratory manual that

no outline is required here. However, its simplicity, clearness, accuracy, and freedom from vagaries are so pronounced as to give the book a peculiar value for its evident purpose.

A final chapter on the "Detection of Substances of Physiological Interest" might with profit have been altogether abandoned or replaced by a short treatment of some one of the more important subjects (such as applications of the polarimeter, nucleic acids) which have been omitted in the interest of brevity. The last chapter is in such contrast to the remainder of this excellent book as to suggest the expression "examinations in medicine" used by the author in his preface.

WALTER JONES.

UNTERSUCHUNG UND NACHWEIS ORGANISCHER FARBSTOFFE AUF SPEKTROSKOPISCHEM WEGE. VON JAROSLAV FORMÁNEK, Tit. Professor in der k. k. böhmischen technischen Hochschule, Inspektor an der k. k. allgemeinen Lebensmitteluntersuchungsanstalt der böhmischen Universität. Unter Mitwirkung von DR. EUGEN GRANDMOUGIN, Professor im eidgenössischen Polytechnikum in Zürich. Zweite, vollständig umgearbeitete und vermehrte Auflage. Erster Teil. Mit 19 Textfiguren und 2 lithogr. Tafeln. Berlin: Verlag von Julius Springer. 1909. pp. viii + 257. Price, M. 12.

The book entitled "Spektralanalytischer Nachweis künstlicher organischer Farbstoffe," which was published by Professor Formánek in 1900, marked the first attempt to introduce spectral analysis as a general method in the study of dye-stuffs. Since then, this method has gained many adherents. Of the importance of the spectroscope in this field of chemistry, there is no longer any doubt. In a private communication to the author, Dr. Robert E. Schmidt, Director of the Farbenfabriken vorm. Fr. Bayer und Co., says: "In fact, I introduced the spectroscope into my laboratory almost twenty years ago and it has been of the greatest help to us in our work. Many discoveries would never have been made without this little instrument, and the manufacture of many products would be impossible without its aid." In the present book, after a general discussion of the spectroscopic method, absorption spectra of colored solutions, the influence of various factors, such as solvents, concentration, temperature, reagents, etc., on the spectra, Professor Formánek takes up the relations between color absorption, fluorescence and the constitution of colored bodies in general. He then discusses the relations between the constitution and absorption spectra of the following classes of dyes: di- and triphenylmethane dyes, fluorindene and triphenyldioxazin, acridin dyes, and anthraquinone dyes. In Part II., which is to appear soon, will be described the spectroscopic method of analysis of the most

important commercial dyestuffs and mixtures of them, together with their absorption spectra.

C. A. R.

ION. A Journal of Electronics, Atomistics, Ionology, Radioactivity, and Raumchemistry. Edited by FREDERICK SODDY and CHARLES H. WALTER, in consultation with Sv. ARRHENIUS, W. H. BRAGG, A. S. EVE, O. HAHN, W. H. JULIUS, A. WERNER, G. BRUNI, MD. CURIE, GUILLEAUME, VAN'T HOFF, W. MARCKWALD, M. WIEN.

This will be recognized as another new journal, and of the making of scientific journals, as of the making of books, there seems to be no end. The scope of this journal is indicated by the title and sub-title. The latter cannot be regarded as ideal English, and is not consistent. "Raumchemistry" would hardly pass in any country which used the English language, especially since the word admits of such easy translation. The inconsistency of "Electronics, atomistics, ionology," is obvious. Give us either "Electronics, atomistics, ionistics," or perhaps the less euphonious "Electronology, atomology, ionology." The reason for starting this journal, together with its aim, is stated thus by Mr. Walter. After calling attention to the richness of German scientific literature, and the influence of the German journals on the development of the special branches of science in that country, Walter says that "although physico-chemistry is an established department of science, it has no particular organ to represent it in England; and English authors had to rely upon the papers and magazines of various societies, whose columns were open to numerous other studies as well. Ion will be, therefore, the Physico-Chemical Journal of Britain."

Here again the tendency to manufacture words manifests itself. The term physical chemistry has pretty well established itself, and is not likely to give place for some time to physico-chemistry, or to anything else; and why should it, since the former is certainly more euphonious than the latter.

The contents of this number are inviting. A brief sketch of Becquerel is followed by a paper by Soddy on "The Charge Carried by the α -Particle." There is also a very interesting paper by Joly on "Uranium and Geology," and a contribution by Julius on the "Transmission of Energy in the World of Electrons."

Hahn and Meitner also have a paper on "Actinium C, A New Quickly Decaying Product of Actinium."

The number contains also several "reports" on matters of interest, especially in the field of radioactivity. May this journal meet with all the success that it deserves. H. C. J.

ELEKTROLYTISCHE ZÄHLER. Von DR. KONRAD NORDEN. Halle a/S: Verlag von Wilhelm Knapp. 166 pp., 130 illustrations. 1908. Price, M. 9.

The thirty-third of a series of monographs on applied chemistry. In view of the present narrow use of the electrolytic meter in the sale of electric power the purpose of the work is the investigation of the limits imposed on the meter by its principles, and of the degree in which the requirements of practice may be met.

In Part I the qualities demanded of the practical electric meter are first treated. The conditions and limits of accuracy, overload, no load, power loss, variation of voltage, are considered at length. The suitability of the electrolytic cell as based on Faraday's laws for meeting all these conditions then follows. The principal objections to the use of the electrolytic meter are unsuitability to three-wire service and two-rate service and entire exclusion from alternating current service.

In Part II the electrolysis of the salts of copper, zinc, silver, mercury, and the electrolysis of water are treated with special consideration of inherent peculiarities as affecting the permanency and constancy of a meter. A valuable feature of this part are the lists of references covering the literature on each type of electrolytic cell. A discussion of the work of the investigator is frequently given.

Part III contains extensive descriptions of the most important types of electrolytic meter which have appeared, with frequent references to patents and literature. The difficulties met in practice with each type are discussed. Some fifty or sixty types involving solid, liquid and gaseous decomposition products are described.

Since the accepted standard of current is defined in terms of the electrolytic deposition of silver, and since the most convenient and accurate laboratory methods for the measurement of current are those of electrolysis, it would appear that the principles involved in these methods would find valuable application in commercial measuring instruments. Many early attempts, notably those of Edison, were made to produce such instruments but the necessary conditions of accuracy and reliability are not met in the circumstances under which such meters are used. Electrolytic meters are practically unknown in this country, and constitute, according to Dr. Norden, less than 5 per cent of the total number of meters abroad. The work is valuable in that it collects for the first time the results of experience with this type of apparatus.

J. B. WHITEHEAD.

AMERICAN CHEMICAL JOURNAL

[Contributions from the Chemical Laboratory of Cornell University.]

TETRACHLORGALLEIN AND SOME OF ITS DERIVATIVES.

BY W. R. ORNDORFF AND T. G. DELBRIDGE.

HISTORICAL.

Tetrachlorgallein was first prepared by Graebe¹ in 1887 in the course of his investigation of tetrachlorophthalic acid. It was made by heating tetrachlorophthalic anhydride with pyrogallol to 190°–200°, extracting the mass with hot alcohol, precipitating the tetrachlorgallein with water and again crystallizing it from alcohol. The product thus prepared and purified forms a violet-colored, crystalline powder. Analyses of this substance dried at 100° gave results which agree with the formula $C_{20}H_6O_7Cl_4 \cdot 2H_2O$, while when dried to constant weight at 180° it had the composition indicated by the formula $C_{20}H_6O_7Cl_4$. These formulas are based on determinations of carbon and hydrogen only and the analytical data are not given, so that it is not possible to recalculate the results. It is quite evident, however, that Graebe assigned this formula to tetrachlorgallein from its analogy to gallein to which Buchka² had given the formula $C_{20}H_{10}O_7$.

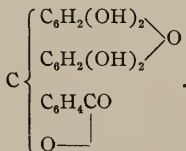
¹ Ann. Chem. (Liebig), **238**, 337 (1887).

² *Ibid.*, **209**, 264 (1881).

in 1881. From tetrachlorgallein Graebe obtained a crystalline, almost colorless acetyl compound, which, on analysis, gave him results agreeing approximately with the formula $C_{20}H_4O_7Cl_4(OCCH_3)_4$. This formula is deduced from two determinations of carbon and hydrogen and one of chlorine, no analytical data being given. The percentages of these elements found differ considerably from those required by the theory and it is clear that this formula was assigned to the acetate by Graebe because of its analogy to Buchka's gallein acetate, which has the formula $C_{20}H_8O_7(OCCH_3)_4$. It is but fair to point out that Graebe was studying tetrachlorophthalic acid and some of its derivatives and took up the preparation of tetrachlorgallein only incidentally, so that it is not at all surprising that he confined himself merely to proving that tetrachlorophthalic anhydride combines with pyrogallol to form a compound analogous to gallein.

Since this work of Graebe, no further investigation of tetrachlorgallein has been made.

Gallein itself had been previously discovered and studied by Baeyer¹ who regarded it as pyrogallolphthalein anhydride, $C_{20}H_{12}O_7$, analogous to fluorescein, which it closely resembles. The following formula would therefore express its constitution according to Baeyer:

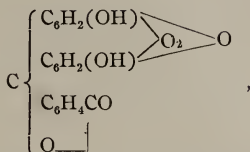


Gallein according to Baeyer.

Later, in 1881, Karl Buchka,² working in Baeyer's laboratory, took up the detailed study of gallein and coerulein after Baeyer had determined the structure of phenolphthalein and Emil Fischer that of fluorescein. Buchka assigned to gallein the formula

¹ Ber. d. chem. Ges., **4**, 457, 658; Ann. Chem. (Liebig), **202**, 36.

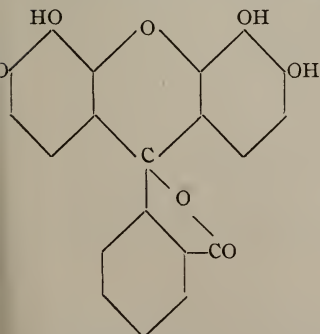
² Ann. Chem. (Liebig), **209**, 255 (1881).



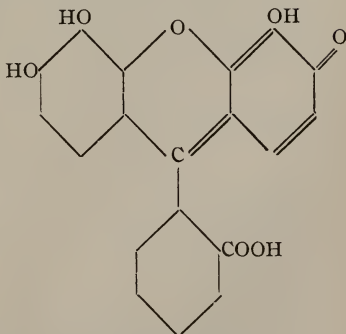
Gallein according to Buchka.

assuming that in the formation of this substance two of the hydroxyl groups belonging to the pyrogallol residue are oxidized to a quinone group, analogous to the formation of cedrret by the oxidation of the dimethyl ether of pyrogallol.

This formula was generally accepted until 1900 when Orndorff and Brewer¹ published the results of their investigation on gallein and coerulein. They found that gallein is not a quinonelike compound as represented in the above formula by Buchka, but is the true anhydride of pyrogallolphthalein, analogous to fluorescein, as first suggested by Baeyer, and has the formula $\text{C}_{20}\text{H}_{12}\text{O}_7$. It is a tautomeric substance, according to these authors, yielding two classes of derivatives, colored compounds having the quinoid structure and colorless compounds with the lactoid structure. Free gallein has the quinoid structure. The following formulas represent the tautomeric modifications of gallein:



Lactoid formula.

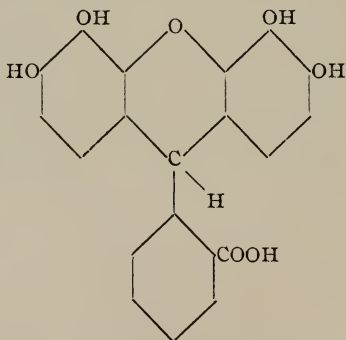


Quinoid formula.

Gallein.

¹ THIS JOURNAL, 23, 425, and 26, 97.

In accord with the lactoid formula is the fact that gallein forms a *colorless* tetracetate, *colorless* trimethyl-, triethyl-, tetramethyl- and tetraethyl ethers not saponified by caustic alkalies, and a *colorless* trimethyl ether monacetate. Gallein also forms *colored* mono-esters which are readily saponified and must therefore have the quinoid structure, *colored* tetramethyl- and tetraethyl ethers which give on saponification *colorless* trimethyl- and triethyl ethers and hence must also have the quinoid formula. When heated with phenyl isocyanate, gallein forms a colored triphenylcarbamate having acid properties, thus showing the presence of three phenol hydroxyl groups and a carboxyl group in the molecule. On reduction with zinc dust in acid or alkaline solution, according to Orndorff and Brewer, gallein gives only one product, gallin, to which they assign the formula



Gallin according to Orndorff and Brewer.

since it gives a colorless tetracetate which is an acid forming a colorless silver salt, and also because it yields a colorless pentamethyl ether.

The subject of the constitution of the phthaleins and their salts has recently received the attention of a number of investigators, and on account of the bearing of these researches

on the question of the constitution of tetrachlorgallein the more important papers which have appeared since 1900 are briefly reviewed here.¹

Nietzki and Schröter² had prepared the colored, quinoid carboxyl ester of fluorescein in 1895 by the oxidation of fluorescein ethyl ester. This method is, however, indirect. A direct method of obtaining this ester by heating fluorescein with alcohol and sulphuric acid was discovered in 1901 by Feuerstein and J. Wallach,³ who thus obtained a colored, quinoid carboxyl ester identical with the one described by Nietzki and Schröter. This colored ester gave a monacetate which was also colored. This work establishes the quinoid formula for the free fluorescein.

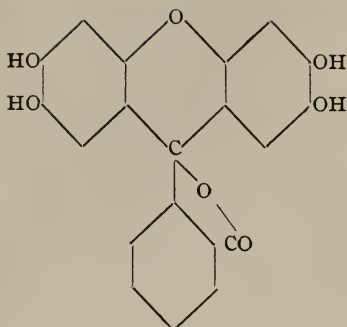
In 1901 three independent investigations⁴ were published on oxyhydroquinonephthalein. This substance is isomeric with gallein, and like gallein it is tautomeric, forming colored carboxyl esters which have the quinoid formula and are easily saponified with alkalis, and also a colorless tetracetate which must have the lactoid formula. Like gallein the oxyhydroquinonephthalein is a colored compound and gives colored esters with alcohols and sulphuric acid, hence it must have the quinoid formula. It is a mordant dye, as might have been predicted since it contains two hydroxyl groups in the ortho position to each other. With sulphuric acid it condenses to violein, a compound resembling coerulein made from gallein by the action of sulphuric acid. The tautomeric forms are represented in the following formulas:

¹ For a review of the literature of the phthaleins previous to 1900 the reader is referred to Orndorff and Brewer's article on Gallein and Coerulein, *THIS JOURNAL*, **26**, 97.

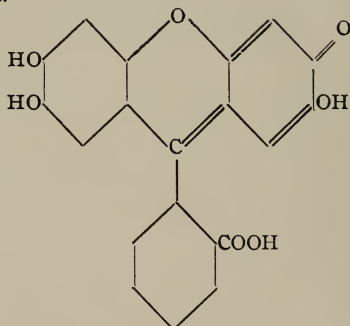
² *Ber. d. chem. Ges.*, **28**, 45 (1895).

³ *Ibid.*, **34**, 2641 (1901).

⁴ C. Liebermann: *Ibid.*, **34**, 2299; J. Thiele and C. Jäger: *Ibid.*, **34**, 2617; W. Feuerstein and M. Dutoit: *Ibid.*, **34**, 2637.



Lactoid formula.



Quinoid formula.

Oxyhydroquinonephthalein.

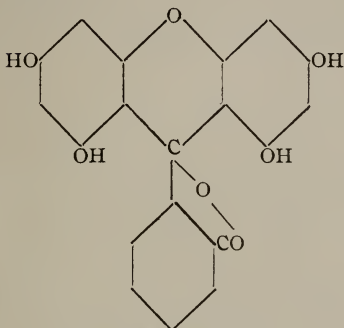
Oxyhydroquinonephthalein dissolves in sodium acetate solution to form a yellowish brown fluorescent solution which becomes fuchsine-red on the addition of alkalis. Only the mono-salts apparently fluoresce.

In 1902 Herzig and Pollak¹ attempted to determine whether the phthaleins in the *free* state have the lactoid or quinoid formula by making use of diazomethane to introduce the alkyl groups. Phenolphthalein gave the lactoid dimethyl ether, fluorescein the quinoid dimethyl ether, hence the first

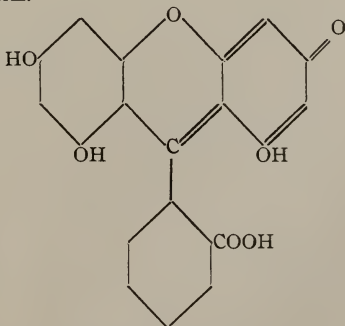
¹ Monatsh. Chem., **23**, 709.

has the lactoid and the second the quinoid formula in the free¹ state.

Phloroglucinphthalein was studied in 1903 by C. Liebermann and Th. Zerner.¹ Since the compound crystallized from water in practically colorless needles, the lactoid formula (I) was assumed for it. On drying at 120° this colorless product loses 21 to 25 per cent. of water and becomes orange-yellow. To this form they therefore assign the quinoid formula (II).



I. Colorless, lactoid form.

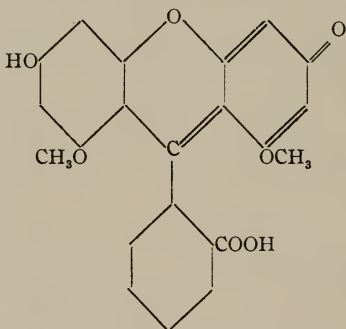


II. Colored, quinoid form.

Phloroglucinphthalein.

¹ Ber. d. chem. Ges., **36**, 1070.

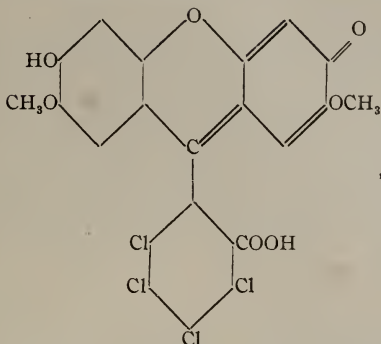
The substance is extremely soluble in alcohol, acetic acid, acetone and boiling water with an orange-yellow color but without fluorescence. Alkalies and the alkaline carbonates dissolve it with a deep orange-red color but these solutions show no fluorescence. A colorless tetracetate and tetrabenzoate were made and also the faintly colored tetrabromphloroglucinphthalein corresponding to eosin. The colored dimethyl ether is soluble in alkalies with an extremely strong yellowish-green fluorescence which may be explained by assuming for the ether in alkaline solution the following formula which shows its analogy with fluorescein:



Dimethyl ether of phloroglucinphthalein.

In 1903 Osorovitz¹ condensed oxyhydroquinone with the halogen substituted phthalic anhydrides. The oxyhydroquinonetetrachlorphthalein forms green crystals with a metallic luster which dissolve in sodium bicarbonate solution with a rose color and greenish fluorescence, whereas in alkalies they dissolve with a red color but without fluorescence. The colored dimethyl ether, however, dissolves in alkalies with a fluorescence resembling that of fluorescein, and its alcoholic solution is also fluorescent. As this dimethyl ether does not color mordants, two free hydroxyl groups in the ortho position are not present and the compound probably has the structure

¹ Ber. d. chem. Ges., **36**, 1076 (1903).



Dimethyl ether of oxyhydroquinonetetrachlorophthalein (colored).

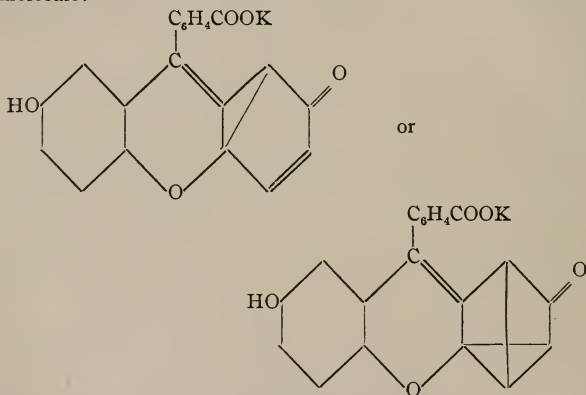
which is in accord with its close resemblance to fluorescein. Osorovitz found that the oxyhydroquinonetetrachlorophthalein does not yield an ester with alcohol and sulphuric acid and suggests that this may be due to the fact that the two ortho positions to the carboxyl group are occupied and therefore, in accordance with the Victor Meyer rule, the compound should not give an ester. All the ethers prepared by Osorovitz were colored and the tetramethyl ether dissolves in alcohol with marked fluorescence similar to that of the dimethyl ether. Oxyhydroquinonetetrachlorophthalein is a tautomeric substance, as it yields a colorless tetracetate, which must have the lactoid formula, in addition to the colored quinoid ethers mentioned above and the red calcium and barium salts. It is isomeric with tetrachlorgallein made by Graebe.

In 1903 R. Meyer and O. Spengler¹ published the results of their investigations on the constitution of the salts of the phthaleins. Meyer² had previously determined the structure of hydroquinonephthalein by making dinitrofluoran, converting it into diaminofluoran by reduction, and this into dioxyfluoran by diazotizing and heating with water. This dioxyfluoran, which was identical with hydroquinone-

¹ Ber. d. chem. Ges., **36**, 2949.

² R. Meyer and H. Meyer: *Ibid.*, **28**, 2559 (1895); R. Meyer and L. Friedland: *Ibid.*, **31**, 1739 (1898).

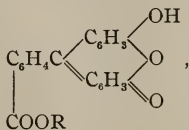
phthalein, is hence an isomer of fluorescein. It resembles phenolphthalein, however, and not fluorescein in its conduct. In the free state it is colorless but dissolves in alkalis with an intense violet-red color and without fluorescence. The question of the constitution of these colored salts of hydroquinonephthalein presents greater difficulties than in the case of the salts of the other phthaleins, for if they are represented as having the metaquinoid structure, one of the following atomic combinations must be assumed within the molecule:



Potassium salt of hydroquinonephthalein.

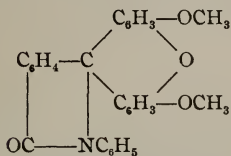
The fact that metaquinones are unknown constitutes, according to Meyer and Spengler, a strong objection to these formulas.

If the hydroquinonephthalein can appear in a quinoid form, then the existence of a carboxyl ester,

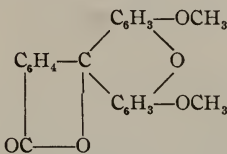


is to be expected. Meyer and Spengler tried to make this

ester by first reducing hydroquinonephthalein to the phthalin, converting it into the ester, and then oxidizing this, but no definite product resulted. They also failed to obtain the ester by heating hydroquinonephthalein with alcohol and sulphuric acid. They then investigated the esterification of the hydroquinonephthalein in alkaline solution, but obtained a colorless dimethyl ether, insoluble in alkali, to which they assigned the lactoid formula (II), as the same ether resulted when the anilide of the phthalein was methylated (I) and aniline afterward split off:

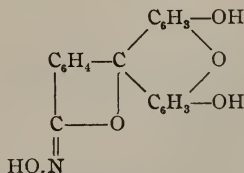
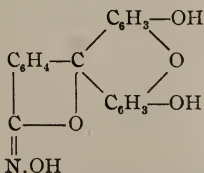


I. Dimethyl ether of hydroquinonephthaleinanilide.



II. Dimethyl ether of hydroquinonephthalein.

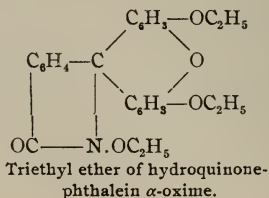
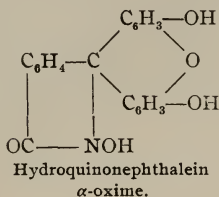
They then took up the action of hydroxylamine on an alkaline solution of hydroquinonephthalein and found that three oximes are formed. The main product (α) is colorless and dissolves in alkalis without color and without fluorescence, the two others (β and γ), formed in much smaller quantity, are yellowish-brown. One of them (β) dissolves in methyl alcohol with an intense greenish fluorescence and may be converted into the compound (γ), which does not fluoresce, from which it may be assumed that these two oximes are stereoisomeric. In later articles¹ they give the following stereo formulas for these two oximes:



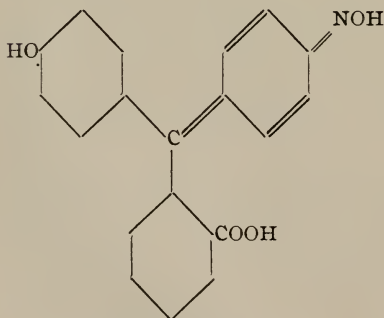
β - and γ -Hydroquinonephthalein oximes.

¹ Ber. d. chem. Ges., **38**, 1318 and **42**, 2825.

The α -oxime was converted in alkaline solution into the colorless triethyl ether insoluble in alkalis. They therefore assign the following formulas to these compounds:

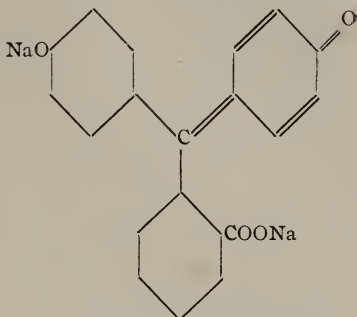


They then undertook a study of the yellow phenolphthalein oxime, first prepared by Friedländer¹ by treating an alkaline solution of phenolphthalein with hydroxylamine hydrochloride. To this yellow compound Friedländer gave the formula (I):



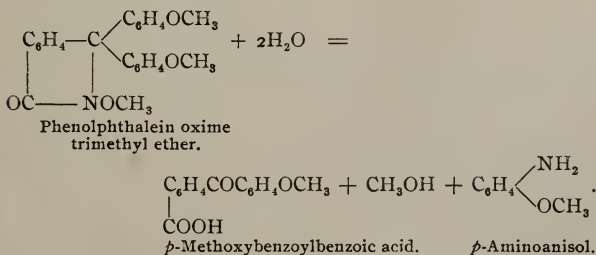
I. Phenolphthalein oxime.

¹ Ber. d. chem. Ges., 26, 172 and 2258.

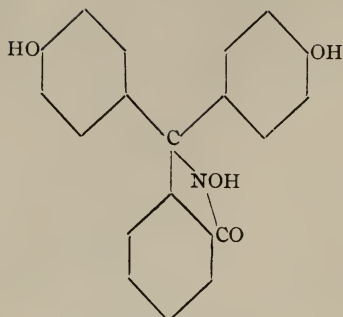


II. Sodium salt of phenolphthalein.

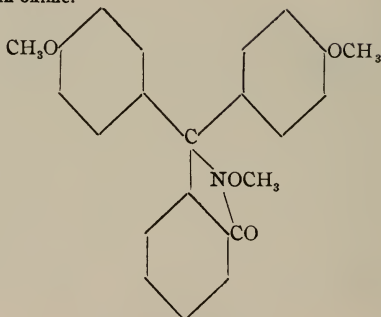
The formation of this colored oxime was at first considered an important confirmation of the quinoid formula of the salts of phenolphthalein (II). Meyer and Spengler show that the oxime forms a practically colorless trimethyl ether when its strongly alkaline solution is shaken with dimethyl sulphate and that this trimethyl ether undergoes saponification with alcoholic caustic potash, yielding a colorless dimethyl ether of the oxime soluble in acids as well as in alkalis. With acids the trimethyl ether splits up into *p*-methoxybenzoylbenzoic acid, methyl alcohol and *p*-aminoanisole, as shown in the following equation:



From these facts it follows that in phenolphthalein oxime there are still present *two* phenol hydroxyl groups. They therefore give the following formulas to the oxime and its trimethyl ether:



Phenolphthalein oxime.



The trimethyl ether.

They conclude that, contrary to the generally accepted view, the colored salts of the phthaleins are not quinoid but lactoid in structure and they uphold this view in a later article.¹

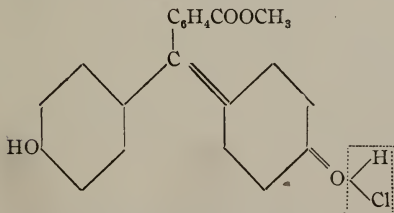
Baeyer,² after a thorough study of the colored saltlike compounds of triphenylcarbinol, concludes that they do not contain a quinoid group and he approves of the view of Meyer and Spengler that, from the closely agreeing conduct of hydroquinonephthalein and phenolphthalein, the colored salts of these substances also do not contain a quinoid group. He applies his theory of the carbonium isomerism to the phthaleins

¹ Ber. d. chem. Ges., **38**, 1318 (1905).

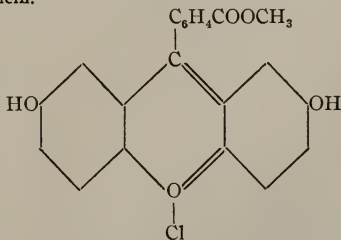
² *Ibid.*, **38**, 569 (1905).

and gives formulas for the sodium salts of phenol- and hydroquinonephthaleins, representing them as containing an ionizable carbonium valence which he regards as the cause of color in these salts. As Baeyer¹ has now abandoned this theory, no further mention of it need be made here.

The views of Meyer and Spengler concerning the constitution of phenol- and hydroquinonephthalein salts were disproved by Green and King² who succeeded in making colored quinoid esters of these two phthaleins. Nietzki and Burckhardt³ had previously prepared colored quinoid esters of tetrabromphenolphthalein by oxidation of the esters of tetrabromphenolphthalin. This method is, however, so indirect that it can hardly be regarded as a proof of the tautomerism of phenol- and hydroquinonephthalein. Green and King prepared their esters in the form of chlorides, by dissolving the phthaleins in methyl alcohol and passing in hydrochloric acid gas. They give to the chlorides of the two phthalein methyl esters the following formulas:



I. Hydrochloride of the methyl ester of phenolphthalein.



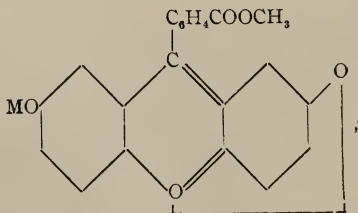
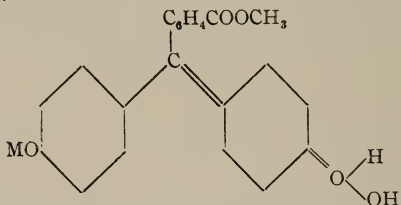
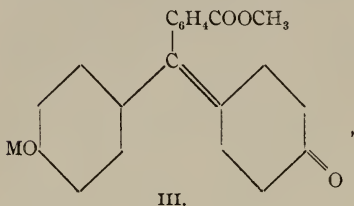
II. Chloride of the methyl ester of hydroquinonephthalein.

¹ Ann. Chem. (Liebig), **354**, 152 (1907). See also Ber. d. chem. Ges., **42**, 2624.

² Ber. d. chem. Ges., **39**, 2365 (1906) and **40**, 3724 (1907).

³ *Ibid.*, **30**, 175 (1897).

Hydrochloric acid can be split off the hydrochloride of the methyl ester of phenolphthalein (I) with ammonia and an orange-red ester is obtained which is more stable than the hydrochloride. The hydroquinonephthalein ester could not be obtained in the free state as it is very unstable. Its chloride (II) is, however, more stable. Contrary to expectations these esters dissolve in alkalis without saponification with a violet-red color. To these salts they give the formulas



in which M represents the metal. Formula IV is given the preference over III as it brings out better the resemblance

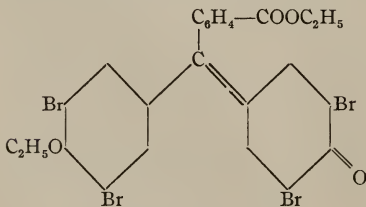
which exists between both classes of salts. They give to the colored metallic salts of phenolphthalein and hydroquinonephthalein, in which the resemblance in color points to an analogy in structure, similar formulas, simply replacing the methyl group by the metal. They conclude that the differences between phenol- and hydroquinonephthalein on the one hand and fluorescein on the other are only of degree. In all three the phenomenon of tautomerism is shown; while, however, the peculiar grouping in the two first named phthaleins is the lactoid form, that of fluorescein appears to be the quinoid. The cause of the color is the same in all three.

A. Hantzsch,¹ in his work on the isomerism of the nitrophenol salts and the existence of metaquinoid compounds, has called attention to the fact that the salts of the colorless *m*-nitrophenol can be obtained in two distinct modifications, one red and the other yellow. Hence in the formation of colored salts from the colorless mother substance an intramolecular rearrangement must also be assumed to take place in the meta series. This fact furnishes a direct proof of the existence of metaquinoid compounds, against the assumption of which much has been said even very recently. For even if one of the two *m*-nitrophenol salts is regarded as a normal nitrophenol salt (notwithstanding its marked color), still, on account of the existence of the second isomer, the assumption of an isomerized nitrophenol salt is unavoidable. Hence, according to Hantzsch, there certainly exists also in the meta series of compounds the same atomic rearrangement as he has proved to exist in the ortho and para series (*e. g.*, in the case of the aniline dyestuffs) and which he has designated as quinoid transformations. In answer to the objection against the assumption of such metaquinoid salts that simple metaquinones or their derivatives (quinone-imides, quinone-oximes) are not known and perhaps are really not capable of existence, Hantzsch points out that there is a difference between metaquinones and metaquinoid salts which may explain the existence of the latter in spite of the nonexistence of the former. The metaquinones should be

¹ Ber. d. chem. Ges., 40, 339.

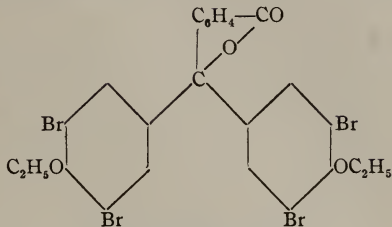
indifferent, electrically neutral compounds. The metaquinoid salts are formed from the colorless hydrogen compounds by the action of a positive metal, which isomerizes the nitrophenols to quinoid derivatives of nitric acid, or these salts exist in solution as ions, *i. e.*, as electrically charged complexes. Hence in all probability the metaquinoid condition can only be made stable in the case of electrolytes under the compulsion of a positive metal (or negative radical) or by taking up electric charges. By making these metaquinoid nitrophenol salts, Hantzsch removed the last objection to the metaquinoid formula for the salts of hydroquinonephthalein.

R. Meyer and K. Marx,¹ in commenting on the work of Green and King, call attention to the fact that these chemists made their esters from the phthaleins themselves by acid alkylation and not from the salts of the phthaleins and, on this account, they say that even this valuable result can not be regarded as a certain proof of the quinoid nature of the phthalein salts. They also call attention to the fact that Hantzsch did not work with the phthaleins but extends his conclusions drawn from the nitrophenols to these substances. They therefore endeavored to make the quinoid esters directly from the silver salt of the phthalein according to the method used by Hantzsch in making his ethers of the nitrophenols. By treating the *blue* disilver salt of tetrabromphenolphthalein suspended in dry benzene with dry ethyl iodide, they obtained the yellow, quinoid diethyl ether of tetrabromphenolphthalein, identical with the compound previously prepared by Nietzki and Burckhardt, to which they give the following formula (I):



I. Quinoid ether (colored).

¹ Ber. d. chem. Ges., **40**, 1437.



II. Lactoid ether (colorless).
Diethyl ether of tetrabromophenolphthalein.

This colored ether (I) changes over with the greatest ease into the colorless lactoid ether (II) (just as is the case with Hantzsch's quinoid nitrophenol ether), so that it was impossible for them to obtain it entirely free from its isomer, which was also plainly the case with Nietzki and Burckhardt. R. Meyer and Marx thus prepared a quinoid phenolphthalein derivative directly from a phthalein salt. This, according to them, had never been previously accomplished.¹ Later R. Meyer and Marx² prepared the diethyl ether ester of phenolphthalein itself from the solid dipotassium salt and found that it is intensely yellow and changes on recrystallizing into the stable, colorless lactone di-ether. They also studied the absorption spectra of the alkali salts of phenolphthalein, hydroquinonephthalein and fluorescein in neutral aqueous solution and found that while the spectra of the three phthaleins at approximately the same concentration and also the colors of their solutions have a very different appearance, the curves which are obtained when the wave lengths of the absorbed light are represented as functions of the concentration are exactly alike.

K. H. Meyer and A. Hantzsch³ investigated the salts of phenolphthalein and its lactoid and quinoid ethers with acids. The red sulphate of phenolphthalein they could not obtain in crystalline form nor could they isolate a hydrochloride of definite composition. It was shown that phenolphthalein

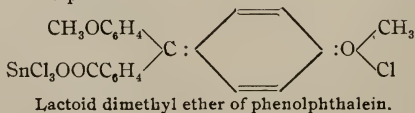
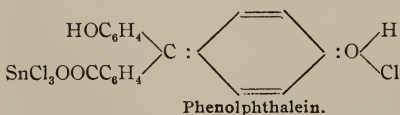
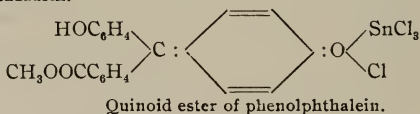
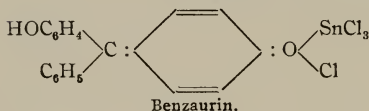
¹ In 1901 Orndorff and Brewer prepared colored quinoid ethers of gallein from the alkali salts with alkyl iodides. See *THIS JOURNAL*, **26**, 137.

² *Ber. d. chem. Ges.*, **40**, 3603.

³ *Ibid.*, **40**, 3479.

took up hydrochloric acid at -30° , at the same time turning red. On warming, this compound was decolorized and lost all of the absorbed acid. With aluminum chloride and tin tetrachloride, however, phenolphthalein forms beautiful red double salts of the formulas $C_{20}H_{14}O_4AlCl_3$ and $C_{20}H_{14}O_4SnCl_4$. These double salts are, according to Straus,¹ A. Werner,² and others, perfectly analogous to the colored salts with the inorganic acids. The lactoid dimethyl ether of phenolphthalein and also the quinoid monomethyl ester of Green and King form similar colored salts and the absorption spectra are practically the same. This leads to the conclusion, according to K. H. Meyer and Hantzsch, that all the acid salts of the phenolphthalein group are quinoid. They give the following formulas to the tin chloride double salts:

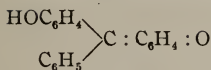
Tin tetrachloride double salts with



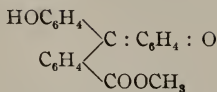
They also call attention to the close resemblance of benzaurin and the quinoid ester of phenolphthalein, as shown in the following formulas:

¹ Ber. d. chem. Ges., **37**, 3277.

² Neuere Anschauungen auf dem Gebiete der anorgan. Chemie, S. 91.



I. Benzaurin.



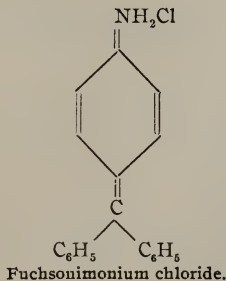
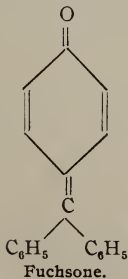
II. Quinoid phenolphthalein ester.

The ester (II) forms red-violet alkali salts, just as benzaurin and phenolphthalein do. Since the alkali salts of phenolphthalein have the same color as those of its quinoid ester we must, according to these authors, also assign the quinoid formula to them. This is in harmony with the observation of Nietzki and Burckhardt¹ that their quinoid tetrabromphenolphthalein ethyl ester forms *blue* alkali salts.

After a very thorough investigation of the derivatives of triphenylcarbinol Baeyer² draws the following conclusions concerning the connection between color and chemical composition in the case of those compounds containing only one oxy or amino group in each benzene ring:³

1. All carbinols are colorless. Color only appears in consequence of the elimination of water from the molecule.

2. Only the para monosubstitution products are capable of losing water. From the *p*-oxytriphenylcarbinol the orange-colored fuchson is obtained, while the hydrochloric acid salt of *p*-aminotriphenylcarbinol gives the like colored fuchsonimonium chloride:



¹ Ber. d. chem. Ges., **30**, 175 (1897).

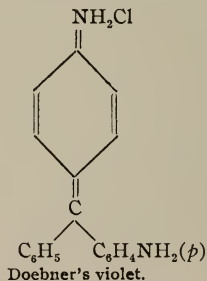
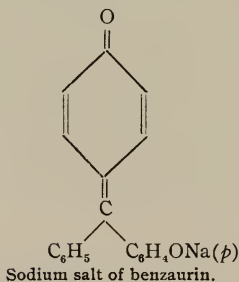
² Ann. Chem. (Liebig), **354**, 152.

³ Derivatives of triphenylcarbinol containing only one oxy or amino group in each benzene ring Baeyer designates as singular, those containing two groups as binary, and those containing three as ternary.

3. The singular¹ disubstitution products of the oxygen series and of the nitrogen series conduct themselves differently.

a. Only those oxygen compounds lose a molecule of water which contain at least one oxy group in the para position. There are thus formed *p*-, *o*- or *m*-oxyfuchsones exactly analogous to fuchsones. In alkalis all three dissolve with intense color, violet, bluish red, and blood-red. Only the *p-p'*-form is stable in alkaline solution and only this solution shows a characteristic spectrum—the spectrum of benzaurin.

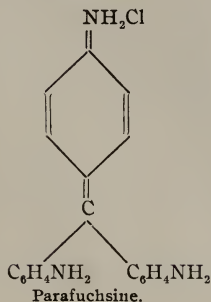
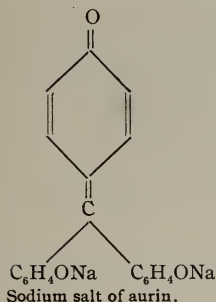
b. The hydrochloric acid salts of the singular diamino-triphenylcarbinols resemble the alkaline salts of the oxyfuchsones in that only the *p-p'*-form (Doebner's violet) gives a characteristic spectrum identical with the benzaurin spectrum:



The *p-m'*-compound conducts itself like the mono-*p*-amino-compound and in the *p-o'*-form the tinctorial effect of the *p*-amino group is actually diminished. The forms containing no *p*-amino groups do not give the slightest color in acid solution.

4. Of the singular trisubstitution products only aurin is known in the oxygen series and this gives in alkaline solution a characteristic spectrum very much like that of benzaurin:

¹ See foot-note 3 on page 203.

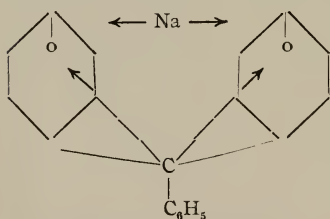


Parafuchsine, in the nitrogen series, corresponds to aurin and its solution shows the same spectrum as the alkaline aurin solution. The condition necessary for the formation of a colored salt is the presence of two amino groups in the para position as is shown by *o*-aminomalachite green, which contains only two amino groups in the para position. All the other triaminotriphenylcarbinols dissolve in acids either quite without color or at most with an orange-yellow color.

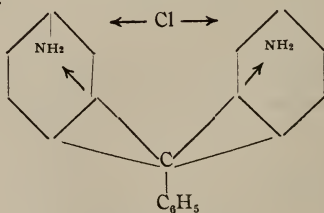
5. The total result is, therefore, that at least two oxy or amino groups must be present in the para position in order to bring about the characteristic spectrum, a sharply bordered narrow band. The typical substances are therefore the sodium salt of benzaurin and Doebner's violet on the one hand, and the sodium salt of aurin and *p*-fuchsine on the other.

Baeyer then attempts an explanation of the color of the aniline and aurin dyestuffs as follows: the formation of the aniline dyes is due to the presence of at least two amino groups in the para position. We may also formulate this as follows: If we designate in the diaminotriphenylcarbinol the amino-benzene rings by *a* and *b*, then it is immaterial whether *a* or *b* goes over into the quinoid form and the quinoid form *a* can go over into the quinoid form *b* without changing the nature of the substance. It is conceivable, therefore, that a continuous oscillation takes place which may give rise to rhythmic ether vibrations of a definite wave length and thus

produce a characteristic spectrum. The same reasoning holds for the sodium salt of benaurin. It might be urged against this theory that the transformation of an aniline residue into a quinoid group is such a complicated process that the rapid repetition of the same can scarcely be assumed to take place, especially in the solid dyestuff. This objection disappears, however, if we return to the old Graebe quinone formula for the methylenequinone, which was first suggested for fuchsine by Emil and Otto Fischer and which has not yet been proved to be incorrect. The following figures, in which the long arrows indicate the fourth valence of the central carbon atom oscillating to and fro, show plainly that the process may be referred to a simple vibration of the central carbon atom, since the oscillation of the sodium or the chlorine ion to and fro does not introduce the slightest difficulty, according to the electrolytic dissociation theory:



Sodium salt of benaurin.



Doebner's violet.

The same reasoning holds for the sodium salt of aurin and for *p*-fuchsine, in which the oscillation in three benzene rings takes place.

This review outlines the most recent work on the phthaleins. Tetrachlorgallein was chosen as the subject of this investigation for the following reasons:

1. In order to test the correctness of the formula assigned to gallein by Orndorff and Brewer.¹
2. To study the effect upon the phthaleins of introducing negative groups into the phthalic acid radical.
3. To throw additional light on the subject of the phthaleins in general.
4. To study the relation between color and constitution in these compounds and to determine the cause of the color.

EXPERIMENTAL.

The pyrogallol used in this investigation was obtained from Kahlbaum. It was perfectly white, melted at 131° – 132° (uncor.),² and left no residue on ignition. It dissolved in ether and in alcohol without color and the aqueous solution was only faintly pink. The tetrachlorphthalic anhydride used was prepared by heating tetrachlorphthalic acid for about thirty hours at 105° , the acid having been carefully purified by the method already described.³

Tetrachlorgallein.

This compound was first prepared according to the directions of Graebe⁴ by heating tetrachlorphthalic anhydride with pyrogallol at 190° – 200° . The product obtained in this way was so impure and the yield so small that this method was abandoned. Freshly fused and powdered zinc chloride proved to be an extremely efficient condensing agent and its use is indispensable in obtaining a high yield of the tetrachlorgallein. After many experiments, the following method of preparation was finally adopted: 286 grams (1 molecule) of pure tetrachlorphthalic anhydride and 265 grams (2.1 molecules) of pyrogallol were *thoroughly* mixed by grinding and sifting, transferred to a two-liter balloon flask contain-

¹ THIS JOURNAL, 26, 137.

² The melting points given in this paper were taken with a thermometer compared with one standardized by the Physikalisch-technisches Reichsanstalt.

³ Delbridge: THIS JOURNAL, 41, 403.

⁴ Ann. Chem. (Liebig), 238, 337 (1887).

ing 137 grams (0.5 molecule) of *finely* powdered zinc chloride, and the mixture made as intimate as possible by stirring and shaking. The flask, closed by a perforated cork carrying a loosely fitting thermometer, was half immersed in a bath of concentrated sulphuric acid whose temperature was kept at 200° – 210° throughout the whole operation. The contents of the flask melted at 130° – 140° to a viscous, reddish colored liquid which was kept well stirred with the thermometer. Steam soon filled the flask, driving out the air and thus preventing oxidation of the tetrachlorgallein and of the pyrogallol. The temperature rose rapidly to 175° and a vigorous reaction took place, marked by frothing and the evolution of much steam. The temperature remained constant at 175° – 176° for about thirty minutes and then rose slowly to 190° , the melt becoming more viscous and darker colored. After the mass had been heated for thirty minutes longer at 190° – 195° , it became almost solid and the flask was removed from the bath, filled with carbon dioxide, allowed to cool, and then broken. The hard, greenish colored reaction product was separated from the broken glass, ground in a mill, and the resulting dark brown powder kept in tightly stoppered bottles.

The removal of zinc chloride was accomplished in two ways. In the earlier part of the investigation, the powdered reaction product was extracted with boiling two per cent. hydrochloric acid until the extract no longer contained zinc, and the residue, after thorough washing with water, was dried at room temperature. The crude tetrachlorgallein obtained in this way was a reddish brown powder which dissolved completely in sodium hydroxide and in acetone, a fact which showed that no carbonaceous matter had been formed in its preparation. The water in this product was determined by drying to constant weight in an atmosphere of carbon dioxide at 157° (cumene), using the apparatus already described.¹ It was found in the beginning of this investigation that tetrachlorgallein and many of its derivatives are very readily oxidized in the air even at comparatively low

¹ Delbridge: *THIS JOURNAL*, **41**, 403.

temperatures. In this respect these compounds resemble pyrogallol, of which they are really derivatives. For this reason the apparatus above mentioned was used in *all* cases where these compounds were heated. Without some such device it would have been impossible to obtain many of the results given in this paper.

Substance. Gram.	Loss. Gram.	Water. Per cent.
0.5559	0.0210	3.78
0.6297	0.0241	3.83
Calculated ¹ for $C_{20}H_8O_7Cl_4 \cdot H_2O$,		3.47

Chlorine in this product dried at 157° was determined by the modification of the lime method described in another paper.² 0.2559 gram of the substance required 20.37 cc. of tenth-normal silver nitrate solution.

	Calculated for $C_{20}H_8O_7Cl_4$.	Found.
Cl	28.26	28.23

This product was not pure tetrachlorgallein hydrate, however, as it was found to contain a small amount of tarry, noncrystallizable impurities which gave a dirty red color with caustic alkali solution.

In the latter part of the investigation the removal of zinc chloride was effected by a method which made it possible to separate the crude product into two fractions, one of which was almost pure. The finely ground reaction product obtained in the preparation of the compound was shaken for several minutes with an equal weight of *cold* methyl alcohol and the undissolved material filtered off and washed with cold methyl alcohol until it was free from zinc. This residue had a light salmon color and was found to be practically pure tetrachlorgallein. The methyl alcoholic filtrate was strongly acidified with hydrochloric acid and diluted with ten times its volume of water to precipitate all the tetrachlorgallein. The precipitate was thoroughly washed with hot water and dried at room temperature. It had a dark brown color and

¹ International Atomic Weights for 1909 have been used in all calculations.

² Delbridge: "Tetrachlorophthalic Acid," *THIS JOURNAL*, 41, 393.

contained impurities giving a dirty red color with sodium hydroxide solution. This impure fraction constituted about 18 per cent. of the total crude product obtained by the methyl alcohol purification, and the remaining 82 per cent. was practically pure, as stated above.

The average yield of crude tetrachlorgallein was about 83 per cent. of the theoretical, as shown in the following table:

	Tetrachlorphthalic anhydride. Grams.	Crude tetrachlor- gallein. Grams.	Yield of $C_{20}H_8O_7Cl_4 \cdot H_2O$. Per cent.
I	286	430	83
II	278	427	84
III	715	1102	85
IV	715	1062	82

Zinc chloride was removed from IV by the methyl alcohol treatment, but from the others by extraction with hot dilute hydrochloric acid.

Pure tetrachlorgallein was prepared from this crude product by repeated crystallization from methyl alcohol. The compound was thus obtained in reddish brown, granular crystals containing varying amounts of alcohol and water. These crystals were dried to constant weight at 157° in an atmosphere of carbon dioxide in the apparatus to which reference has been made above.¹ Determinations of chlorine in this dried material gave the following results:

Substance. Gram.	Tenth-normal silver nitrate. cc.	Chlorine. Per cent.
0.2908	23.05	28.11
0.2621	20.84	28.19
0.2629	20.89	28.18
Calculated for $C_{20}H_8O_7Cl_4$,		28.26

This anhydrous tetrachlorgallein has only a faint reddish color. It is practically insoluble in water, benzene, chloroform, ether, ligroin and carbon bisulphide. In alcohol, acetone, acetic acid and ethyl acetate it dissolves with a faint red color which becomes deep red on the addition of a little water. Tetrachlorgallein is much more soluble in

¹ Page 208.

methyl alcohol than in ethyl alcohol and the crystals from the former contain methyl alcohol. Solutions of sodium and potassium hydroxides dissolve tetrachlorgallein with an intense blue color, while the solution in ammonia is bluish purple. Solutions of the alkali carbonates and bicarbonates dissolve tetrachlorgallein in the cold, carbon dioxide being evolved. The color of the solution is claret-red when an excess of the phthalein is present, but deep purple with an excess of the carbonate. This fact indicates that there are at least two series of alkali salts, one dissolving with a red color and the other with a purple color. Solutions of sodium acetate and borax dissolve tetrachlorgallein with a reddish purple color. From the *freshly* prepared alkaline solutions, acids precipitate tetrachlorgallein hydrate in red microscopic crystals, but if the alkaline solution is allowed to stand in the air it is rapidly oxidized and turns yellow, and acids then give no precipitate.

Tetrachlorgallein differs from gallein in that it is practically insoluble in an aqueous solution of pyrogallol and also in a solution of hydrochloric acid (sp. gr. 1.1). Gallein dissolves readily in this hydrochloric acid and if the hot solution be filtered gallein hydrochloride crystallizes out of the filtrate in beautiful needle-shaped crystals, red by transmitted light and green in reflected light. Gallein is therefore much more basic than tetrachlorgallein.

When tetrachlorgallein is exposed to ammonia gas it turns red at once and then almost black, forming an ammonium salt which dissolves in water with a bluish purple color. Dry hydrochloric acid gas also combines with solid tetrachlorgallein, forming a dark red hydrochloride which is decomposed by heat or by water. The aluminum salt of tetrachlorgallein has a violet color, the copper and iron salts are purple, and the lead and barium salts are dark blue. These salts are all only slightly soluble in water. A number of attempts were made to prepare a silver salt of tetrachlorgallein but metallic silver was formed in every case, a further indication of the ease with which this phthalein is oxidized.

Heated to 320° tetrachlorgallein does not melt but gives

off hydrochloric acid slowly even below this temperature, while at higher temperatures it yields a reddish colored sublimate whose nature was not investigated.

The color of crystallized tetrachlorgallein varies, with the conditions of crystallization, from faint pink to a deep red, so that color gives no reliable indication as to the purity of the product. An easy method for testing the purity of the compound consists in boiling a little of it with acetic anhydride for about five minutes. Pure tetrachlorgallein gives a pale lemon-colored solution, the presence of impurities being denoted by a red or brown color. The various forms of tetrachlorgallein are being further investigated and a colorless modification has been prepared, probably a carbinol-carboxylic acid.

Tetrachlorgallein Hydrochloride.

This compound was prepared by passing dry hydrochloric acid gas into a cooled solution of ten grams of pure tetrachlorgallein in 150 cc. of dry acetone. The precipitate which separated was filtered off, washed with a little dry acetone, and kept over sulphuric acid. The product thus obtained consisted of small prismatic crystals, red to transmitted light but green to reflected light. The green luster is destroyed by grinding or by exposure to moist air. A weighed portion of the compound was placed in a platinum boat and heated in the drying apparatus to 157° (cumene) in a current of hydrogen. The outflowing gases were passed through cold water in a Hugershoff gas washing bottle with flat glass spiral, and the amount of hydrochloric acid given off was determined by titration with tenth-normal sodium hydroxide solution, phenoltetrachlorophthalein¹ being used as indicator. The substance left in the boat was then weighed and it was found that the total loss of weight was much greater than the weight of hydrochloric acid found on titration. This difference was due to loss of acetone, identified by its odor, by conversion into iodoform, and by the formation of acetone phenylhydrazone. The residue left in the boat had a faint pink

¹ Orndorff and Black: *THIS JOURNAL*, **41**, 349; Delbridge: *Ibid.*, **41**, 401.

color and gave all the reactions of tetrachlorgallein. Chlorine in this residue was determined with the following results:

Substance. Gram.	Tenth-normal silver nitrate. cc.	Chlorine. Per cent.
0.2597	20.51	28.01
0.3009	23.82	28.07
Calculated for $C_{20}H_8O_7Cl_4$,		28.26

On account of the fact that the hydrochloride contained some acetone of crystallization, the hydrochloric acid found on titration is expressed as grams of hydrochloric acid per hundred grams of tetrachlorgallein.

Tetrachlorgallein left in boat. Gram.	Tenth-normal sodium hydroxide. cc.	Hydrochloric acid. Grams per 100.
0.1851	3.43	6.76
0.3014	5.78	6.99
Calculated for $C_{20}H_8O_7Cl_4.HCl$,		7.27

The difference between the hydrochloric acid found and the calculated amount is due to the fact that the product had lost a little hydrochloric acid before the analysis was made. It is evident, however, that this compound is a *mono*-hydrochloride with acetone of crystallization.¹ This hydrochloride is decomposed quantitatively by hot water and the hydrochloric acid liberated may be determined by direct titration with tenth-normal sodium hydroxide solution, the tetrachlorgallein serving as the indicator. Analyses:

Substance. Gram.	Anhydrous tetra- chlorgallein. Gram.	Tenth-normal sodium hydroxide. cc.	Hydrochloric acid. Grams per 100.
0.5335	0.4897	9.35	6.96
0.5028	0.4616	8.80	6.95
0.5335	0.4897	9.39	6.99
Calculated for $C_{20}H_8O_7Cl_4.HCl$,			7.27.

Monosodium Salt of Tetrachlorgallein.

For the preparation of this compound 20 grams of tetrachlorgallein were suspended in three liters of boiling water in a five-liter balloon flask, and the mixture was kept boil-

¹ Heller and Langkopf have prepared a "Salzsaures Galleinacetanat" to which they give the formula $C_{20}H_{12}O_7.HCl.C_3H_5O$ (Z. Farb. Ind., 5, 115).

ing vigorously while a solution of 1.5 grams of pure anhydrous sodium carbonate in 100 cc. of water were added gradually. The solution became claret-red at once and carbon dioxide was evolved. After the mixture had been boiled vigorously for thirty minutes, the excess of tetrachlorgallein was filtered off as rapidly as possible, the solution filtered again, and the filtrate concentrated to about 900 cc. by distillation in a flask. Evaporating dishes could not be used for this purpose because the hot solution is too easily oxidized by the air. The deep red solution was allowed to stand for two days and the dark colored crystalline substance which separated was filtered off, washed with cold water, and dried to constant weight at room temperature. A number of attempts were made to determine the water of crystallization in this product by drying at various temperatures in a Victor Meyer oven but the loss of weight was continuous and it was found that the salt is oxidized in the air at temperatures above 100° . It was this difficulty which led to the construction of the drying apparatus described in another paper.¹ Water of crystallization in the sodium salt was finally determined in this apparatus by drying to constant weight in a current of carbon dioxide at 160° (cumene).

Substance. Gram.	Loss. Gram.	Water. Per cent.
0.3155	0.0407	12.90
0.1967	0.0254	12.91
Calculated for $C_{20}H_7O_7Cl_4Na \cdot 4H_2O$,		12.09

On drying to constant weight *in vacuo* over phosphorus pentoxide, results were obtained which indicate that the sodium salt retains a half molecule of water under these conditions.

Chlorine and sodium were determined in the compound dried to constant weight at 160° :

Substance. Gram.	Silver chloride. Gram.	Chlorine. Per cent.
0.2158	0.2348	26.92
0.2028	0.2202	26.86
Calculated for $C_{20}H_7O_7Cl_4Na$,		27.07

¹ THIS JOURNAL, 41, 403.

Substance. Gram.	Sodium sulphate. Gram.	Sodium. Per cent.
0.2455	0.0311	4.10
0.3054	0.0391	4.15
Calculated for $C_{20}H_7O_7Cl_4Na$,		4.39

These analyses, together with the method of preparation, show clearly that the compound is the monosodium salt of tetrachlorgallein. The air-dried material is almost black and has a bronzy luster. The crystals were too small for a crystallographic examination but appear under the microscope as slender prisms showing a marked tendency to felt together. The dried salt has a red color. The compound dissolves in water with a claret-red color, but partial hydrolysis takes place and some tetrachlorgallein is precipitated. There is a possibility, therefore, that the sodium salt made in aqueous solution contains traces of tetrachlorgallein, and in order to overcome this objection a sodium salt was prepared by the following method:

Pure anhydrous tetrachlorgallein (16.4 grams) was dissolved in a mixture of 250 cc. of acetone and 500 cc. of 94 per cent. ethyl alcohol, both freshly distilled. This solution was filtered and kept boiling vigorously in a flask connected with a return condenser while a filtered solution of 4.2 grams of pure crystallized sodium acetate in 100 cc. of 94 per cent. alcohol was added rather slowly through the condenser. A heavy, dark colored precipitate was formed and after the mixture had been boiled for twenty minutes this precipitate was filtered off with suction, washed thoroughly with hot acetone to remove the last traces of tetrachlorgallein, and dried to constant weight at room temperature. The sodium salt obtained in this way was beautifully crystallized, consisting of slender transparent prisms which had a brownish black color with a bronzy luster. Like the sodium salt made in aqueous solution this compound dissolved in water with a claret-red color and was partially hydrolyzed, some tetrachlorgallein being precipitated. The substance was dried to constant weight in carbon dioxide at 157° (cumene) and then analyzed for sodium and chlorine. The sodium was

determined by conversion into sodium sulphate and also by a much more rapid volumetric method conducted in the following manner: A weighed portion of the salt was suspended in 200 cc. of cold water in a porcelain dish and a measured excess of tenth-normal hydrochloric acid solution added at once. The mixture was heated on a steam bath for a few minutes to insure complete decomposition of the sodium salt and then titrated with tenth-normal sodium hydroxide solution. The tetrachlorgallein served as a delicate indicator, the slightest excess of alkali being denoted by a rose-red color. Analyses:

Substance. Gram.	Sodium sulphate. Gram.	Tenth-normal hydrochloric acid. cc.	Sodium. Per cent.
0.6101	0.0794	.....	4.21
0.4555	0.0596	.....	4.24
0.9894	.....	18.28	4.25
1.1089	.....	20.54	4.26
Calculated for $C_{20}H_7O_7Cl_4Na$,			4.39

Substance. Gram.	Tenth-normal silver nitrate. cc.	Chlorine. Per cent.
0.2759	21.00	26.99
0.2936	22.36	27.01
Calculated for $C_{20}H_7O_7Cl_4Na$,		27.07

Hence this compound is the monosodium salt of tetrachlorgallein.

Tetrachlorgallein dissolves in an excess of sodium hydroxide with a deep blue color, probably forming a *tetrasodium* salt. This salt could not be isolated, however, because it is very rapidly oxidized by the air.

There are two facts which indicate that tetrachlorgallein can form at least two salts with sodium carbonate solution: (1) When an excess of tetrachlorgallein is used the solution has a claret-red color and contains a *monosodium* salt as shown above, but with an excess of sodium carbonate the solution is purple and probably contains a di- or trisodium salt of tetrachlorgallein. (2) The monosodium salt of tetrachlorgallein is much more soluble in sodium carbonate solu-

tion than in water. Accordingly a number of attempts were made to prepare a di- or trisodium salt in various ways but in every case the product obtained was so rapidly oxidized in the air that analysis was useless.

Monopotassium Salt of Tetrachlorgallein.

This compound was prepared in aqueous solution from 30 grams of tetrachlorgallein and 2.7 grams of anhydrous potassium carbonate by the same method used in making the monosodium salt.¹ It resembles the sodium salt very closely in its appearance and properties. The air-dried material gave the following results on analysis:

Substance. Gram.	Silver chloride. Gram.	Chlorine. Per cent.
0.2961	0.2763	23.08
0.3946	0.3664	22.97
0.3495	0.3260	23.07
Calculated for $C_{20}H_7O_7Cl_4K \cdot 4H_2O$, 23.17		

Substance. Gram.	Potassium sulphate. Gram.	Potassium. Per cent.
0.3761	0.0514	6.13
0.3296	0.0454	6.18
0.3727	0.0510	6.14
Calculated for $C_{20}H_7O_7Cl_4K \cdot 4H_2O$, 6.39		

Hence this compound is the monopotassium salt of tetrachlorgallein and, like the sodium salt, contains four molecules of water of crystallization. The determination of this water of crystallization showed that the potassium salt, like the sodium salt, retains a half molecule of water when dried over phosphorus pentoxide to constant weight *in vacuo* (I) or in carbon dioxide at 80° (II):

	Substance. Gram.	Loss. Gram.	Water. Per cent.
I	0.5766	0.0592	10.27
II	0.4020	0.0412	10.25
Calculated for $3\frac{1}{2}H_2O$ in $C_{20}H_7O_7Cl_4K \cdot 4H_2O$, 10.30			

All the water is driven off by drying to constant weight

¹ Page 213.

in hydrogen at 157° (cumene), as shown by the following analyses made on the air-dried material:

Substance. Gram.	Loss. Gram.	Water. Per cent.
0.3525	0.0414	11.74
0.4711	0.0552	11.72
Calculated for $4\text{H}_2\text{O}$ in $\text{C}_{20}\text{H}_7\text{O}_7\text{Cl}_4\text{K} \cdot 4\text{H}_2\text{O}$,		11.77

Extraction with acetone showed that the potassium salt prepared as described above contained a trace of tetrachlorogallein, although the solution from which it was crystallized was perfectly clear. An attempt was therefore made to purify this salt by recrystallization from water. The recrystallized product was dried to constant weight at room temperature and analyzed:

Substance. Gram.	Silver chloride. Gram.	Chlorine. Per cent.
0.2491	0.2427	24.10
0.2739	0.2660	24.02

Mean, 24.06

Substance. Gram.	Potassium sulphate. Gram.	Potassium. Per cent.
0.2694	0.0305	5.08
0.3089	0.0351	5.10
0.2650	0.0308	5.22
0.3110	0.0358	5.17

Mean, 5.14

The ratio of chlorine to potassium in this salt shows clearly that potassium was removed by crystallization from water:

	Per cent.	Atomic weight.	Ratios.
Cl	24.06	$\div 35.46$	$= 0.6785 - 4.000$
K	5.14	$\div 39.10$	$= 0.1315 - 0.775$
Chlorine : potassium :: 4.000 : 0.775.			

This loss of potassium is doubtless due to the hydrolysis of the monopotassium salt with the formation of tetrachlorogallein, the ratio found corresponding to that in a mixture of one molecule of tetrachlorogallein and three molecules of its monopotassium salt. It is evident that the salts of tetra-

chlorgallein can not be purified by crystallization from water but must be made from pure materials.

The monopotassium salt of tetrachlorgallein was also prepared by adding a solution of 7 grams of pure crystallized potassium acetate in 200 cc. of 94 per cent. ethyl alcohol to a boiling solution of 35 grams of pure anhydrous tetrachlorgallein in 1000 cc. of alcohol. The precipitate which formed was filtered off, washed thoroughly with hot alcohol, and dried to constant weight at room temperature. Analyses:

Substance. Gram.	Potassium sulphate. Gram.	Potassium. Per cent.
0.3965	0.0609	6.89
0.3957	0.0606	6.87

Calculated for $C_{20}H_7O_7Cl_4K \cdot 2H_2O$, 6.79

Substance. Gram.	Tenth-normal silver nitrate. cc.	Chlorine. Per cent.
0.5083	34.86	24.32
0.4833	33.28	24.42

Calculated for $C_{20}H_7O_7Cl_4K \cdot 2H_2O$, 24.62

The properties of this compound were identical with those of the potassium salt made in aqueous solution. Loss of weight on heating was determined in the drying apparatus already described and an examination of the outflowing gases showed that the compound contained no alcohol. On drying to constant weight in carbon dioxide at 110° (toluene), the following results were obtained:

Substance. Gram.	Loss. Gram.	Water. Per cent.
0.2391	0.0116	4.85
0.2549	0.0124	4.86

Calculated for $1\frac{1}{2}H_2O$ in $C_{20}H_7O_7Cl_4K \cdot 2H_2O$, 4.69

Hence this salt resembles those already described in that it holds a half molecule of water quite firmly. All the water is lost at 157° (cumene), as shown by the following analyses:

Substance. Gram.	Loss. Gram.	Water. Per cent.
0.2391	0.0151	6.32
0.2549	0.0158	6.20

Calculated for $2H_2O$ in $C_{20}H_7O_7Cl_4K \cdot 2H_2O$, 6.25

The analytical data already given show very clearly that the potassium salt holds a half molecule of water very firmly, as is also true of the monosodium salt. This conduct is especially interesting in view of the fact that tetrachlorophthalic acid¹ crystallizes from water under all conditions with a half molecule of water.

Tetrachlorgallein Hydrate.

The tetrachlorgallein crystallized from methyl alcohol contains both methyl alcohol and water in varying proportions, depending on the conditions of crystallization. The crude tetrachlorgallein² is evidently a hydrate but is impure.

The preparation of a pure monohydrate of tetrachlorgallein was accomplished in the following manner: Some of the pure monosodium salt was dissolved in boiling distilled water in a flask, and very dilute hydrochloric acid was added drop by drop, the solution being kept boiling vigorously to prevent oxidation by the air. The reddish violet precipitate was filtered off, washed with hot water till free from chloride, and dried to constant weight at room temperature. This product lost one molecule of water when dried to constant weight at 158° (cumene) in a current of carbon dioxide:

Substance. Gram.	Loss. Gram.	Water. Per cent.
0.4313	0.0156	3.62
0.3417	0.0123	3.60
Calculated for $C_{20}H_8O_7Cl_4 \cdot H_2O$,		3.47

Chlorine determinations showed that the material dried at 158° was pure anhydrous tetrachlorgallein.

Substance. Gram.	Tenth-normal silver nitrate. cc.	Chlorine. Per cent.
0.2517	19.99	28.16
0.2931	23.28	28.16
Calculated for $C_{20}H_8O_7Cl_4$,		28.26

¹ Delbridge: THIS JOURNAL, 41, 393.

² Page 209.

These results show that tetrachlorgallein hydrate contains one molecule of water and not two, as found by Graebe. They are also in accord with the results of Heller and Langkopf¹ on gallein hydrate, $C_{20}H_{12}O_7 \cdot H_2O$.

Tetrachlorgallein hydrate is a reddish violet, crystalline meal, consisting, as seen under the microscope, of minute rhomboidal plates. Its solubilities and conduct toward reagents are like those of the anhydrous compound. The hydrate, however, has a marked color, while the anhydrous tetrachlorgallein is nearly colorless. The hydrate is also formed in small amount when the pure monosodium or potassium salt is dissolved in water. Partial hydrolysis takes place, as has been stated before,² and the precipitated tetrachlorgallein hydrate can be filtered off. A further investigation of this hydrate is now in progress.

Lead Salt of Tetrachlorgallein.

When a solution of lead acetate is added to an aqueous solution of tetrachlorgallein monosodium salt, a blue precipitate is formed but the amount is small and some oxidation always takes place. The lead salt was therefore prepared as follows: A hot filtered solution of ten grams of pure tetrachlorgallein in 700 cc. of alcohol (94 per cent.) was slowly added to a boiling solution of 30 grams of pure crystallized lead acetate in 1000 cc. of alcohol. A dark blue precipitate formed at once, and after the mixture had been boiled for a half hour this precipitate was filtered off, transferred to a clean flask, and boiled with about 500 cc. of alcohol. The undissolved material was filtered off, washed with hot alcohol until the filtrate gave no color with hydrogen sulphide, and dried to constant weight at room temperature. The lead salt obtained in this way was a heavy, dark blue, crystalline powder. It is insoluble in alcohol and in water but water removes some lead from the compound, probably by hydrolysis. Dilute mineral acids decompose the salt with the formation of the red tetrachlorgallein hydrate, like that obtained from the

¹ Z. Farb. Ind., 5, 115.

² Pages 215 and 218.

alkali salts. Caustic alkali solutions dissolve the lead salt with a bluish color, but it is practically insoluble in sodium carbonate solution.

The first product (I) made by the method described above was found to yield acetic acid when heated with phosphoric acid. A second product (II) was therefore prepared by the same method, except that the salt was washed with a large amount of hot alcohol in order to make sure that all lead acetate was removed from the material. The total volume of wash alcohol was about nine liters and the last seven liters were practically free from lead. Hence this salt could not have contained any lead acetate, but it still gave acetic acid on distillation with phosphoric acid. Both products were dried to constant weight at 100° and lost about 2.3 per cent. The same loss was found on drying the salt to constant weight *in vacuo* over phosphorus pentoxide.

Analyses of the two products dried at 100° gave the following results, those marked (II) having been obtained with the salt which had been very thoroughly washed with hot alcohol:

	Substance. Gram.	Silver chloride. Gram.	Tenth-normal silver nitrate. cc.	Chlorine. Per cent.
I	0.4222	0.1881	.....	11.02
	0.5610	0.2522	.....	11.12
II	0.6271	.....	20.38	11.52
	0.6346	.....	20.68	11.56
Calculated for $C_{20}H_4O_9Cl_4Pb_3(C_2H_3O)_2$,				11.46

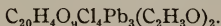
	Substance. Gram.	Lead sulphate. Gram.	Lead. Per cent.
I	0.6004	0.4369	49.71
	0.5561	0.4062	49.90
II	0.3983	0.2925	50.17
	0.5383	0.3965	50.32
	0.3117	0.2293	50.25
Calculated for $C_{20}H_4O_9Cl_4Pb_3(C_2H_3O)_2$,			50.22

The amount of acetyl was determined by decomposing the salt with syrupy phosphoric acid, distilling with steam, and

titrating the acetic acid in the distillate, phenoalpthlein being used as indicator:

	Substance. Gram.	Tenth-normal sodium hydroxide. cc.	C ₂ H ₃ O. Per cent.
I	0.6258	9.63	6.62
	0.5834	8.57	6.32
II	1.3696	14.54	4.57
	1.3514	14.60	4.65
Calculated for C ₂₀ H ₄ O ₉ Cl ₄ Pb ₃ (C ₂ H ₃ O) ₂ ,			6.95

It seemed likely that the low results on acetyl in the second salt were due to loss of acetic acid by hydrolysis during the continued washing with hot alcohol. The correctness of this view was shown by extracting this second salt with large quantities of hot alcohol and then determining the amount of acetyl in the residue. On analysis, 1.3053 gram of substance required 8.20 cc. of tenth-normal sodium hydroxide solution, thus giving 2.7 per cent. of C₂H₃O, while the amount present before this extraction was 4.6 per cent. Hence this lead salt loses acetic acid on prolonged washing with hot alcohol and the fact that water removes lead from the salt is easily explained, since the acetic acid formed by hydrolysis partially decomposes the salt, yielding a soluble acetate of lead. It is evident, however, from the analytical data that the lead salt of tetrachlorgallein prepared as described has the composition represented by the formula



The lead salt of gallein, C₂₀H₈O₇(PbOH)₄, obtained by Orndorff and Brewer¹ was made in *aqueous* solution and was very thoroughly washed with water. This process, as we have shown, removes acetic acid from the lead salt, which may account for the difference in composition of the two salts. Furthermore, the lead salt of gallein was not analyzed for acetyl groups which may have been present. Tetrachlorgallein is moreover a stronger acid than gallein, which may account for the fact that its lead salt contains only three atoms of lead while the lead salt of gallein contains four. It seems

¹ THIS JOURNAL, 26, 134.

quite likely that if the lead salt of gallein were prepared in *alcoholic* solution it would have a composition similar to that of the lead salt of tetrachlorgallein.

Barium Salt of Tetrachlorgallein.

When tetrachlorgallein and barium carbonate are boiled with water a red solution is formed, but the slight solubility of the barium salt of tetrachlorgallein and the ease with which it is oxidized render this method unsuitable for the preparation of the compound. The barium salt was finally prepared in aqueous solution in the following manner: One liter of water was heated to boiling in a two-liter flask connected with a return condenser, 5.2 grams of pure tetrachlorgallein were added, and then enough normal ammonium hydroxide solution to form a tetrammonium salt (0.68 gram of anhydrous ammonia). The resulting bluish purple solution was filtered as rapidly as possible and kept boiling vigorously while a solution of 6 grams of pure crystallized barium chloride in 300 cc. of water was added rather slowly. A dark brown precipitate separated immediately, and after the mixture had been boiled for about fifteen minutes this precipitate was filtered off, washed with water until free from chloride, and dried to constant weight at room temperature. This air-dried barium salt lost about 11.5 per cent. of water when dried to constant weight at 100°, while the loss of weight *in vacuo* over phosphorus pentoxide was 11.3 per cent.

Analyses of the salt dried at 100° gave the following results:

Substance. Gram.	Barium sulphate. Gram.	Barium. Per cent.
0.3311	0.1091	19.39
0.4551	0.1505	19.46
Calculated for $C_{20}H_6O_7Cl_4Ba.3H_2O$,		19.87
Substance. Gram.	Tenth-normal silver nitrate. cc.	Chlorine. Per cent.
0.2164	13.20	21.63
Calculated for $C_{20}H_6O_7Cl_4Ba.3H_2O$,		20.52

The high chlorine content of this product is probably due to the presence of some tetrachlorgallein formed from the

barium salt by hydrolysis¹ in washing out the excess of barium chloride. Notwithstanding the poor agreement between the calculated percentages and those found on analysis, still the ratio of chlorine to barium is approximately 4:1.

	Per cent.	Atomic weight.	Ratios.
Cl	21.63	÷ 35.46	= 0.610 — 4.00
Ba	19.42	÷ 137.37	= 0.141 — 0.93

This ratio is the more interesting because in the preparation of the salt the materials used were in such a proportion that chlorine : barium : : 4 : 2.14.

An attempt was next made to prepare a pure barium salt by adding a clear solution of barium hydroxide (one molecule) in 85 per cent. alcohol to a filtered alcoholic solution of pure tetrachlorgallein hydrate (two molecules). The barium salt obtained in this way was washed with hot alcohol, in which it is insoluble, and dried to constant weight at 100°. It was a greenish blue in color and seemed to be amorphous. It was slightly soluble in hot water, forming a red solution from which dilute acids precipitated the red tetrachlorgallein hydrate. Analyses:

Substance. Gram.	Barium sulphate. Gram.	Barium. Per cent.
0.4451	0.1453	19.21
0.3928	0.1280	19.18
Calculated for $C_{20}H_6O_7Cl_4Ba.3H_2O$,		19.87

Substance. Gram.	Tenth-normal silver nitrate cc.	Chlorine. Per cent.
0.3498	20.66	20.94
0.3499	20.62	20.90
Calculated for $C_{20}H_6O_7Cl_4Ba.3H_2O$,		20.52

This barium salt, like the one made in aqueous solution, seemed, according to the analyses, to contain some tetrachlorgallein. The ratio of chlorine to barium in the materials used in preparing the compound was 8:1 but the actual ratio

¹ It is to be noted that the monosodium and potassium salts are also hydrolyzed in this manner.

found in the salt was 4:0.95, practically the same as that in the barium salt made in aqueous solution.

The water of crystallization in the barium salt dried at 100° could not be determined with accuracy because its complete removal requires so high a temperature that the salt itself is decomposed. While it has been impossible to prepare a perfectly pure barium salt of tetrachlorgallein, nevertheless the analyses of the two products described above show clearly that the barium salt of tetrachlorgallein has the composition represented by the formula $C_{20}H_6O_7Cl_4Ba \cdot xH_2O$.

The barium salt of oxyhydroquinonetetrachlorphthalein made by Osorovitz¹ also has the composition represented by the formula $C_{20}H_6O_7Cl_4Ba$.

Tetrachlorgallein Tetracetate.

Anhydrous tetrachlorgallein (10 grams), fused sodium acetate (10 grams) and acetic anhydride (40 grams) were boiled together for one hour in a flask connected with a return condenser, the mixture allowed to cool, and then poured slowly into ice water. The light colored oil which separated at first solidified after a short time to a pearl-gray, crystalline cake. This crude acetate was ground with water, filtered off, washed thoroughly with water, and allowed to dry. Benzene proved to be an ideal solvent for crystallizing the compound. The benzene solution was boiled a number of times with small portions of boneblack, filtered carefully, concentrated to a small volume, and then cooled rapidly with constant stirring in order to obtain small crystals which were found to be purer than large crystals formed on gradual cooling. This product was filtered off with suction, washed with a little very cold benzene, and again crystallized from benzene, using the same precautions as before. The acetate thus obtained was perfectly colorless and melted sharply at 255° (uncor.). This melting point was not changed by repeated crystallization from alcohol and from benzene. The compound was dried to constant weight in carbon dioxide

¹ Ber. d. chem. Ges., 36, 1076 (1903).

at 110° and analyzed for chlorine with the following results:

	Substance. Gram.	Silver chloride. Gram.	Tenth-normal silver nitrate. cc.	Chlorine. Per cent.
1	0.3247	0.2784	.....	21.21
2	0.3295	0.2816	.....	21.14
3	0.3749	.....	22.31	21.10
4	0.3806	.....	22.68	21.13
	Calculated for $C_{20}H_5O_7Cl_4(C_2H_3O)_3$,			22.59
	Calculated for $C_{20}H_4O_7Cl_4(C_2H_3O)_4$,			21.18
	Calculated for $C_{20}H_3O_7Cl_4(C_2H_3O)_5$,			19.93

Analyses 1 and 2 were made on a product crystallized from benzene alone while that used in 3 and 4 had been crystallized from benzene, alcohol, benzene, alcohol and benzene, successively. These analyses indicate very clearly that the compound is tetrachlorgallein tetracetate, and this was further proven by determining the number of acetyl groups in the compound analyzed in 3 and 4 above. For this purpose the following modification of the Wenzel¹ method was used: The powdered acetate was placed in a 500 cc. balloon flask closed by a two-hole rubber stopper carrying a separatory funnel whose stem extended to the bottom of the flask and a 30 cm. Vigreux distillation tube connected with a spiral condenser whose lower end dipped into a measured amount of tenth-normal sodium hydroxide solution properly protected from the air. Five cc. of sulphuric acid, 2:1, were added through the funnel and the flask heated in boiling water for thirty minutes, after which five cc. of water were introduced and the heating continued for one hour longer. Twenty-five cc. of the sodium phosphate solution, prepared according to Wenzel's directions, were then added and the acetic acid distilled off with steam passed into the flask through the separatory funnel. This steam was generated from a dilute solution of barium hydroxide and was therefore free from carbon dioxide. Preliminary experiments showed that the Vigreux tube completely removes all entrained liquid, even when the distillation is exceedingly rapid. The volume of the

¹ Monatsh. Chem., 18, 659; compare Orndorff and Brewer: THIS JOURNAL, 26, 121.

distillate was about 400 cc. The excess of sodium hydroxide in this distillate was titrated with tenth-normal hydrochloric acid solution, phenolphthalein being used as indicator. The solution was then acidified with hydrochloric acid, a little starch solution added, and the sulphurous acid determined by titration with tenth-normal iodine solution. Under these conditions the presence of the small amount of phenolphthalein has no effect on the results. The following analyses were made by this method on the acetate dried to constant weight at 110° .

Substance. Gram.	Tenth-normal iodine. cc.	Net tenth-normal sodium hydroxide. cc.	C_2H_3O . Per cent.
0.3675	0.25	21.90	25.64
0.3786	0.00	22.55	25.62

Calculated for $C_{20}H_4O_7Cl_4(C_2H_3O)_4$, 25.69

Tetrachlorgallein tetracetate is very soluble in acetone, acetic acid and hot benzene, much less soluble in alcohol, ether, chloroform and cold benzene, while in ligroin it is practically insoluble. When the hot benzene solution is allowed to cool slowly, large transparent crystals are formed which lose benzene in the air, becoming opaque and eventually crumbling to a white powder. Heated in a capillary melting point tube, the acetate dried at 110° undergoes a marked contraction at 155° – 160° but melts sharply at 255° (uncor.). The corrected melting point, taken with an Anschütz thermometer (250° – 300°), was found to be 261° .

Cold five per cent. sodium carbonate solution has at first no apparent action on tetrachlorgallein tetracetate, but on standing the solution gradually acquires a pink color and at the same time shows a green fluorescence. This pink color and green fluorescence become very marked on the addition of a little alcohol. On longer standing the solution becomes purple and the fluorescence disappears entirely. These color changes are evidently due to gradual saponification of the acetate, and the compound dissolving with a pink color and green fluorescence is probably a sodium salt of a tetrachlorgallein diacetate analogous in structure¹ to fluorescein.

¹ Compare the conduct of the tetrachlorgallein methyl ester acetate, page 241.

Solutions of sodium hydroxide saponify the tetrachlorgallein tetracetate slowly in the cold, rapidly on warming, forming a deep blue solution which is rapidly oxidized in the air. Dry hydrochloric acid gas has no apparent effect on the solid tetrachlorgallein tetracetate. Concentrated sulphuric acid dissolves the compound even in the cold, forming a deep red solution, and if this solution is diluted with water, a dull lavender precipitate is formed which gives all the color reactions of tetrachlorgallein. Unlike the form of tetrachlorgallein already described, this lavender precipitate is soluble in ether and the ethereal solution, on evaporation, gives crystals which are white at first but slowly turn pink in the air. Colorless crystals showing this same peculiar conduct were also obtained by crystallizing the lavender precipitate from acetone. Further investigation of this lavender precipitate is necessary in order to determine whether it is really a new form of tetrachlorgallein or a partially acetylated compound.

Tetrachlorgallin Tetracetate.

An attempt was made to prepare tetrachlorgallin by a method similar to that used by Buchka¹ in the preparation of his so-called hydrogallein, shown by Orndorff and Brewer² to be identical with gallin. Tetrachlorgallein was dissolved in a small excess of potassium hydroxide solution in an atmosphere of hydrogen, and zinc dust added cautiously to the cold solution. The mixture was allowed to stand for one hour but no change could be observed and so it was heated for one hour at 50°. The blue color gradually disappeared and the brown solution was cooled, made acid with sulphuric acid, and extracted with ether. The aqueous solution, however, contained chloride in large amount, showing that chlorine had been removed from the tetrachlorgallein during the reduction. The experiment was therefore repeated, the mixture being kept in an atmosphere of hydrogen at room temperature all the time. There was no apparent change during the first two days, but after that time the color changed grad-

¹ Ann. Chem. (Liebig), 209, 251.

² THIS JOURNAL, 26, 125.

ually from blue to brown, two weeks being required for the complete disappearance of the blue color. Although the temperature had never exceeded 25° , chlorine was split off in this experiment, as in the preceding one, and this method was therefore abandoned.

An attempt was next made to prepare tetrachlorgallin acetate by the method used by Orndorff and Brewer¹ in the preparation of gallin tetracetate. A mixture of 10 grams of tetrachlorgallein, 10 grams of sodium acetate, 5 grams of zinc dust and 80 grams of acetic anhydride was boiled on a sand bath for three hours, cooled, and poured into ice water. A brown oil separated but the aqueous solution contained chloride in large amount, showing that chlorine is removed from tetrachlorgallein by this method as well as by the action of zinc and potassium hydroxide.

After a number of unsuccessful attempts the tetrachlorgallin acetate was finally prepared by a method which proved to be very satisfactory both in simplicity and in the yield obtained. Ten grams of pure tetrachlorgallein tetracetate were dissolved in 200 cc. of glacial acetic acid in a flask connected with a return condenser, 3 grams of zinc dust and a few drops of copper sulphate solution added, and the mixture boiled on a sand bath until all the tetrachlorgallein tetracetate had been reduced. The method of determining this point was as follows: A small test portion removed with a pipette was diluted with water and the resulting white precipitate filtered off with suction and dissolved in concentrated sulphuric acid by gentle warming. This sulphuric acid solution was then poured into water. If a reddish turbidity was observed, the tetrachlorgallein tetracetate was not all reduced and hence the boiling was continued. Eventually the sulphuric acid solution prepared as described gave absolutely no turbidity when poured into water, indicating that reduction was complete. The time required for this reduction was usually about three hours and the solution contained no chloride, although boiling was continued in one case for ten hours. When the above test showed that reduction was

¹ THIS JOURNAL, 26, 129.

complete, the acetic acid solution was filtered from the undissolved zinc and zinc acetate, concentrated to half its original volume, and poured into ice water. The white flocculent precipitate which separated was filtered off, washed with cold water, and dried on a porous plate.

This crude product was purified by repeated crystallization from 94 per cent. alcohol until the melting point became constant. The compound thus obtained was pure white and melted sharply at 221° – 222° (uncor.). A portion of this product was recrystallized from 80 per cent. acetone and from benzene, successively, but the melting point remained constant, indicating that the compound was perfectly pure. The product crystallized from alcohol was dried to constant weight in the air at room temperature but still contained alcohol of crystallization which was determined by drying to constant weight at 110° in a current of carbon dioxide. The volatilized alcohol was condensed and identified by its odor and by conversion into iodoform.

Substance. Gram.	Loss. Gram.	Alcohol. Per cent.
0.1816	0.0172	9.47
Calculated for $C_{20}H_6O_7Cl_4(C_2H_3O)_4 \cdot 1\frac{1}{2}C_2H_5OH$, 9.32		

The compound dried to constant weight at 110° was analyzed for chlorine:

Substance. Gram.	Tenth-normal silver nitrate. cc.	Chlorine. Per cent.
0.2300	13.74	21.18
Calculated for $C_{20}H_6O_7Cl_4(C_2H_3O)_4$, 21.10		

Tetrachlorgallin tetracetate resembles gallin tetracetate in its properties and conduct toward reagents. It dissolves in cold concentrated sulphuric acid with a red color, and when this solution is diluted with water it becomes colorless at first and then turns green on standing in the air. The sulphuric acid probably saponifies the acetate and then condenses the tetrachlorgallin to tetrachlorcoerulin, giving a colorless solution in water which is oxidized in the air to the green tetrachlorcoerulein. The tetrachlorgallin tetracetate

dissolves in dilute sodium carbonate solution, liberating carbon dioxide and thus conducting itself like an acid. The resulting solution is colorless if protected from the air but turns pink very quickly in the air and shows at the same time a marked greenish fluorescence. This pink color and green fluorescence is doubtless due to simultaneous saponification and oxidation, resulting in the production of the same compounds as those formed from tetrachlorgallein tetracetate¹ under these conditions. The tetrachlorgallin tetracetate itself is rather easily oxidized to tetrachlorgallein tetracetate, as was discovered in an attempt to purify some of the compound which had a faint yellow color although it melted at the proper temperature, 221°. This material was dissolved in 94 per cent. alcohol, the solution boiled with bone-black for fifteen minutes, filtered, and evaporated to crystallization. The crystals thus obtained were white but proved to be pure tetrachlorgallein tetracetate, as shown by the melting point, 255°, by their conduct toward sodium carbonate solution, and by the reddish precipitate formed on adding water to a solution of the crystals in concentrated sulphuric acid. The yield of tetrachlorgallein tetracetate in this case was practically quantitative.

The percentage composition of tetrachlorgallin tetracetate, $C_{20}H_6O_7Cl_4(C_2H_3O)_4$, is practically the same as that of tetrachlorgallein tetracetate, $C_{20}H_4O_7Cl_4(C_2H_3O)_4$, and hence it is impossible to distinguish between these two compounds by analysis. Accordingly the composition and structure of tetrachlorgallin tetracetate were further established by the preparation and analysis of its silver salt.

Silver Salt of Tetrachlorgallin Tetracetate.

That tetrachlorgallin tetracetate is an acid is shown by the fact that it dissolves in sodium carbonate solution with evolution of carbon dioxide. The sodium salt thus formed is too easily decomposed to permit of its isolation. A large number of attempts to prepare a silver salt of tetrachlorgallin tetracetate gave negative results, but this compound

¹ Page 228.

was finally obtained by the following simple method: Commercial acetone was dried with calcium chloride, carefully fractionated through a 40 cm. Vigreux distillation tube, and the main portion, distilling within one-fifth of a degree, boiled for one hour with solid silver nitrate in a flask connected with a return condenser. The acetone was then distilled off and used as the solvent in the preparation of the silver salt of tetrachlorgallein tetracetate. A solution of 5 grams of dried tetrachlorgallein tetracetate in 100 cc. of this acetone was added rapidly to a solution of 25 grams of silver nitrate in a mixture of 25 cc. of water and 125 cc. of the purified acetone. The resulting solution was perfectly clear at first, but within a few minutes fine white crystals began to separate. After the mixture had been allowed to stand for several hours in the dark, these white crystals were filtered off, washed with the purified acetone, and dried in the air. Analysis showed that this material was not pure and it was therefore crystallized from dry benzene previously digested with silver nitrate and carefully distilled. The perfectly white product thus obtained was dried to constant weight at room temperature and analyzed. Dried to constant weight at 110° in carbon dioxide, the air-dried substance lost one molecule of benzene:

Substance. Gram.	Loss. Gram.	Benzene. Per cent.
0.2432	0.0219	9.01
0.3813	0.0347	9.10
Calculated for		
$C_{20}H_5O_7Cl_4(C_2H_3O)_4Ag.C_6H_6$,		9.11

The compound dried to constant weight at 110° was analyzed for silver and chlorine. The silver could not be determined by burning out the organic matter because some silver chloride was always formed. The determination of silver was therefore conducted in the following manner: A weighed amount of the silver salt was dissolved in 94 per cent. alcohol previously purified by digestion with silver nitrate and subsequent distillation. Nitric acid was then added and the silver determined at once by titration with tenth-normal

ammonium sulphocyanate solution, ammonium ferric sulphate being used as the indicator. The results obtained by this method were as follows:

Substance. Gram.	Tenth-normal ammo- nium sulphocyanate. cc.	Silver. Per cent.
0.2213	2.84	13.84
0.3466	4.45	13.85
Calculated for $C_{20}H_5O_7Cl_4(C_2H_3O)_4Ag$,		13.85

Chlorine in the salt dried at 110° was determined by the modification of the lime method already described.¹ Since the compound also contained silver, this method gave only the chlorine in excess of that which combined with the silver to form silver chloride. Hence the total chlorine was computed by adding to the percentage of chlorine found on titration the percentage of chlorine equivalent to the determined silver content of the compound.

Substance. Gram.	Tenth-normal silver nitrate. cc.	Chlorine not com- bined with silver. Per cent.	Chlorine to form silver chloride. Per cent.	Total chlorine. Per cent.
0.2576	9.90	13.63	4.55	18.18
0.3183	12.23	13.62	4.55	18.17
Calculated for				
$C_{20}H_5O_7Cl_4(C_2H_3O)_4Ag$,		13.66	4.55	18.21

The analyses given above show very clearly that this compound is the silver salt of tetrachlorgallin tetracetate and thus furnish a direct proof of the structure of tetrachlorgallin tetracetate itself.

The silver salt of tetrachlorgallin tetracetate, when crystallized from benzene, is perfectly white and has no definite melting point but decomposes at 230° – 240° . It is quite stable toward light, remaining white for many weeks in diffused daylight. It dissolves in alcohol and acetic acid as well as in benzene, but is insoluble in water and in hot dilute nitric acid. Concentrated nitric acid decomposes the compound readily. With solutions of sodium carbonate and sodium hydroxide, reduction takes place with the formation of metallic silver.

¹ Delbridge: *THIS JOURNAL*, 41, 397.

Tetrachlorgallein Tetraphenylcarbamate.

Anhydrous tetrachlorgallein was heated with an excess of phenyl isocyanate for fifteen minutes but the formation of the carbamate was attended by so much charring that the following method was adopted: A mixture consisting of 10 grams of anhydrous tetrachlorgallein, 15 grams of phenyl isocyanate and 300 cc. of anhydrous cumene was boiled vigorously on a sand bath for three hours. The tetrachlorgallein gradually dissolved, forming a brown solution. This was filtered while hot and allowed to cool, being protected from the moisture of the air by a calcium chloride tube. After several hours the tetrachlorgallein phenylcarbamate separated in brownish yellow crystals which were filtered off and washed with a little cold benzene to remove the excess of cumene and phenyl isocyanate. This crude product was allowed to dry and then dissolved in dry ether. The ether solution was concentrated and allowed to stand. A crop of crystals was thus obtained which proved to be mostly diphenylurea (m. p. 235°), notwithstanding the effort to exclude moisture in the preparation of the compound. Further concentration of the ether solution gave a product containing only traces of diphenylurea. This product was crystallized twice more from anhydrous ether and then contained no diphenylurea, as shown by the fact that it dissolved completely in sodium hydroxide solution. This material was dried to constant weight *in vacuo* over sulphuric acid and analyzed. A small portion was heated for one hour at 80° but lost no weight and hence contained no ether of crystallization.

An attempt was made to determine the chlorine in this phenylcarbamate by the lime method, but the silver chloride precipitate was found to contain some silver cyanide. The determination of chlorine was therefore carried out by the Carius method with the following results:

Substance. Gram.	Silver chloride. Gram.	Chlorine. Per cent.
0.2384	0.1371	14.22
0.1474	0.0861	14.44
Calculated for $C_{20}H_4O_7Cl_4(C_6H_5NHCO)_4$,		14.50
Calculated for $C_{20}H_5O_7Cl_4(C_6H_5NHCO)_3$,		16.51
Calculated for $C_{20}H_8O_7Cl_4(C_6H_5NHCO)_5$,		12.92

This compound is therefore tetrachlorgallein *tetraphenyl*-carbamate. Attempts were made to determine nitrogen in this substance by both the Dafert and Gunning modifications of the Kjeldahl method, but neither of these methods are suitable, as the results obtained varied over a wide range, the average being somewhat lower than the calculated value for a tetraphenylcarbamate.

Tetrachlorgallein tetraphenylcarbamate prepared as described is a colorless, well crystallized compound which melts with decomposition at 182° (uncor.). It becomes highly electrified when rubbed and the particles lose this electric charge very slowly. The compound resembles tetrachlorgallein tetracetate in its conduct toward concentrated sulphuric acid, dissolving even in the cold with a deep red color. When this sulphuric acid solution is diluted with water a lavender precipitate is formed like that obtained from tetrachlorgallein tetracetate. Tetrachlorgallein tetraphenylcarbamate dissolves in dilute solutions of sodium carbonate with a pink color and green fluorescence. When heated or on standing, this solution becomes purple, owing to saponification, and loses its fluorescence. Dilute ammonia acts much like sodium carbonate solution, but sodium hydroxide solutions saponify the carbamate very rapidly, giving the deep blue solution characteristic of tetrachlorgallein. Alcohol dissolves the carbamate with a pink color and green fluorescence, but the addition of the slightest trace of acid destroys this color and fluorescence, so that they may be due to the presence of a trace of alkali in the alcohol used.

Tetrachlorgallein Methyl Ester.

Tetrachlorgallein is a fairly strong acid, since it decomposes carbonates and acetates, and so it seemed likely that an ester might be formed on boiling with methyl alcohol and hydrochloric acid. Accordingly 20 grams of pure anhydrous tetrachlorgallein and 200 grams of a three per cent. solution of hydrochloric acid gas in absolute methyl alcohol were boiled together for four hours in a flask connected with a return condenser. The deep red solution was then filtered, cooled and

poured into about six liters of cold water. A reddish black precipitate separated at once and this was filtered off on a muslin filter, washed with cold water till free from hydrochloric acid, pressed out on a porous plate, and dried *in vacuo* over phosphorus pentoxide. This product differed from tetrachlorgallein in that it was soluble in ether, in chloroform and in benzene, none of which dissolves tetrachlorgallein. The ethereal solution, on evaporation, gave small, dark red crystals which were filtered off, washed with ether, and allowed to dry. They were green in reflected light but dark red by transmitted light, and contained ether of crystallization which was partially lost on standing. The compound was dried to constant weight in carbon dioxide at 110° and analyzed for chlorine. The amount found corresponded very closely with that calculated for a *dimethyl* ester, but methoxyl determinations by the Zeisel method showed clearly that the compound contained only *one* methoxyl group. The material dried to constant weight at 110° was therefore heated to 157° and lost *ether* at this temperature. It could not be brought to constant weight, however, owing to decomposition and hence crystallization of the substance from ether was abandoned.

Benzene proved to be an excellent solvent for purifying the ester, and the dry crude product was boiled with benzene, the deep red solution filtered while hot, and allowed to stand in a cool place. After twenty-four hours the ester had separated in very dark red, microscopic crystals which were filtered off, washed with benzene, and dried at room temperature. This product contained benzene of crystallization which was completely driven off by drying to constant weight in carbon dioxide at 157° . This dried substance gave results on analysis which show clearly that it was the *monomethyl* ester of tetrachlorgallein:

Substance. Gram.	Tenth-normal silver nitrate. cc.	Chlorine. Per cent.
0.2490	19.33	27.53
0.2530	19.66	27.55
Calculated for $C_{20}H_7O_7Cl_4(CH_3)$,		27.49

The methoxyl content was determined by the Zeisel method

with the apparatus of Decker.¹ For the complete saponification of the ester it was necessary to use 20 cc. of a mixture of equal volumes of acetic anhydride and hydriodic acid, sp. gr. 1.96.

Substance. Gram.	Silver iodide. Gram.	CH ₃ O. Per cent.
0.3873	0.1743	5.95
Calculated for C ₂₀ H ₇ O ₇ Cl ₄ (CH ₃),		6.01

Hence tetrachlorgallein forms a monomethyl ester when boiled with methyl alcohol and hydrochloric acid. The same ester was also obtained by boiling a mixture of 15 grams of tetrachlorgallein, 100 cc. of methyl alcohol, and 20 cc. of concentrated sulphuric acid for one hour. The formation of an ester by these two methods is especially interesting because, according to the Victor Meyer rule,² tetrachlorgallein ought not to form an ester in this way, since it contains substituents in both the positions ortho to the carboxyl group. Oxyhydroquinonetetrachlorphthalein,³ phenoltetrachlorphthalein and tetrabromphenoltetrachlorphthalein⁴ do not form esters in this way. With tetrachlorgallein, however, esterification takes place rapidly and almost quantitatively. The crude ester made from 5 grams of pure tetrachlorgallein by boiling for four hours with a three per cent. solution of hydrochloric acid in methyl alcohol was extracted with ether, in which tetrachlorgallein is insoluble, and the insoluble residue was found to weigh only 0.2 gram, showing that 96 per cent. of the tetrachlorgallein had been esterified by this treatment.

Tetrachlorgallein methyl ester, crystallized from benzene and dried to constant weight at 157°, is a dark red, crystalline powder with a slight greenish luster. Heated in a capillary melting point tube it imparts a red color to the glass at 240°–250° and melts with decomposition at 285°–290° (uncor.). It is extremely soluble in acetone, alcohol, ethyl acetate, acetic acid and chloroform, less soluble in benzene and ether, and practically insoluble in ligroin. Supersaturated solutions

¹ Ber. d. chem. Ges., **36**, 2895.

² *Ibid.*, **27**, 510, 1580 and 3146. See also J. Am. Chem. Soc., **30**, 1895.

³ Osorovitz: Ber. d. chem. Ges., **36**, 1076.

⁴ Orndorff and Black: *THIS JOURNAL*, **41**, 366 and 382.

of the ester are easily formed by concentration and are rather stable, the separation of the ester often taking place only after long standing. This property is common to most of the derivatives of tetrachlorgallein described in this paper, especially to solutions of the sodium and potassium salts in water and of the tetracetate in benzene.

The conduct of the methyl ester toward alkaline solutions is almost the same as that of tetrachlorgallein itself. Both dissolve in sodium hydroxide solution with a deep blue color, in sodium carbonate and bicarbonate with a purple color, and in sodium acetate solution with a reddish purple color. Solutions of borax dissolve the ester with a bluish color, while tetrachlorgallein gives a reddish purple. Alcoholic solutions of both tetrachlorgallein and its methyl ester give a dark blue precipitate with lead acetate. The ester is not saponified by a dilute solution of sodium hydroxide although the blue color of the solution is just like that given by tetrachlorgallein itself. The truth of this assertion was established by the following experiments: About 0.1 gram of the pure methyl ester was dissolved in 50 cc. of cold tenth-normal sodium hydroxide and the deep blue solution immediately acidified with dilute hydrochloric acid. The red solution thus formed was extracted with ether, whereupon the ether became deep red while the aqueous layer became colorless and perfectly clear. Since tetrachlorgallein is insoluble both in ether and in water, this conduct can be explained only on the basis that the methyl ester dissolves in tenth-normal sodium hydroxide solution without saponification. The above experiment was repeated with some methyl ester to which a little tetrachlorgallein had been added, but the ether extraction left a turbid aqueous solution containing tetrachlorgallein in suspension. In one case a solution of the ester in tenth-normal sodium hydroxide was allowed to stand for one hour, and even then no saponification could be detected although some oxidation had taken place.

A marked difference between tetrachlorgallein and its methyl ester lies in the conduct of these two compounds toward a solution of hydrochloric acid (sp. gr. 1.10). Tetra-

chlorgallein is insoluble in this acid, while the methyl ester dissolves easily, especially in the hot acid, forming a red solution, and when the hot saturated solution is allowed to cool the methyl ester hydrochloride crystallizes out. In this respect the tertachlorgallein methyl ester resembles gallein to a marked degree as might be expected, since the introduction of the positive methyl group into the tetrachlorphthalic acid residue of tetrachlorgallein would tend to neutralize the effect of the negative chlorine atoms.

Feuerstein and Dutoit¹ prepared a triacetate of oxyhydroquinonephthalein ethyl ester and a monacetate of fluorescein ethyl ester by boiling these esters with acetic anhydride and sodium acetate. This method was tried with tetrachlorgallein methyl ester, a mixture of 5 grams of the ester, 5 grams of sodium acetate and 30 grams of acetic anhydride being boiled for thirty minutes. The crude product was precipitated with water, filtered off, and dried at room temperature. By crystallization from a mixture of acetone and petroleum ether a dark red product was obtained which melted at 215°–220° (uncor.) and which was practically insoluble in cold aqueous sodium carbonate, bicarbonate and caustic alkali, although the latter slowly dissolves the substance with a blue color and green fluorescence. It dissolved in alcohol with an orange-yellow color and a green fluorescence which became more marked on the addition of a little sodium carbonate or hydroxide solution. Analysis of the product dried to constant weight at 60° showed that it was a monacetate of the methyl ester. 0.2588 g. substance required 18.61 cc. of tenth-normal silver nitrate solution. Chlorine, calculated for the methyl ester monacetate, 25.43 per cent.; found, 25.50 per cent.

In a second attempt to prepare the methyl ester triacetate, 10 grams of the ester were boiled with 50 grams of acetic anhydride for fifteen minutes, when the color of the solution, which was deep red at first, became orange-yellow. About 25 cc. of methyl alcohol were then added and the solution allowed to stand overnight. The orange colored crystals which had separated were filtered off and recrystallized from benzene. The product thus obtained was practically colorless and melted at 254° (uncor.), showing a marked contrac-

¹ Ber. d. chem. Ges., **34**, 2639.

tion at 160°. These facts indicated that the compound was tetrachlorgallein tetracetate and a determination of chlorine in the substance dried to constant weight at 110° confirmed this view:

Substance. Gram.	Tenth-normal silver nitrate. cc.	Chlorine. Per cent.
0.2757	16.37	21.05
Calculated for tetrachlorgallein tetracetate,		21.18

Tetrachlorgallein methyl ester dissolves in acetic anhydride in the cold with a deep red color which changes to orange after a few days. It seemed likely that this color change was due to the formation of an acetate of the ester, and so water was added to the acetic anhydride solution prepared in this way, and the oil which separated was allowed to solidify. The hard cake was removed and dried. All attempts to crystallize this product from various solvents resulted in failure and it was eventually dissolved in benzene and precipitated with petroleum ether. The material obtained in this manner was a reddish brown powder which melted at 190°–200° and dissolved in alcohol with a marked greenish fluorescence which was increased by the addition of a little alkali. A portion dried to constant weight at 157° was analyzed for chlorine with the following result:

Substance. Gram.	Tenth-normal silver nitrate. cc.	Chlorine. Per cent.
0.2564	17.65	24.41
Calculated for a methyl ester monacetate,		25.43
Calculated for a methyl ester diacetate,		23.65
Calculated for a methyl ester triacetate,		22.10

It is evident from this analysis that the material was a mixture of acetates, and although it was impossible to acetylate the methyl ester completely, yet the fact that this mixture of acetates dissolved in alcohol with fluorescence is important, since neither tetrachlorgallein nor its methyl ester give fluorescent solutions. This conduct is especially interesting in view of the fact that tetrachlorgallein tetracetate gradually imparts a pink color and green fluorescence to solutions of

sodium carbonate or ammonia. The fluorescence in this case is doubtless due to the formation of the sodium salt of a tetrachlorgallein di- or triacetate analogous in structure to the di- or triacetate of the methyl ester and also to fluorescein.

Tetrachlorgallein Methyl Ester Hydrochloride.

Tetrachlorgallein methyl ester dissolves in benzene with a deep red color, and if dry hydrochloric acid gas is passed into this solution, the color becomes purple, and a dark red hydrochloride gradually crystallizes out. This hydrochloride has a green luster when dried and is more stable in the air than tetrachlorgallein hydrochloride. It is slightly soluble in benzene, ether, alcohol and acetone with a reddish purple color. It is only superficially decomposed by cold water and the complete removal of all the hydrochloric acid requires the use of boiling water. The amount of hydrochloric acid found on analysis was somewhat less than that calculated for a monohydrochloride and this was doubtless due to the presence of benzene of crystallization in the compound, but it was impossible to drive off the benzene by heat without some loss of hydrochloric acid.

In order to overcome this difficulty, the hydrochloride was prepared by exposing the pure, finely ground methyl ester to the action of dry hydrochloric acid gas until the weight became constant. Hydrochloric acid was taken up rapidly with evolution of heat, the amount of acid absorbed being greater than that calculated for a monohydrochloride. The product thus formed lost some hydrochloric acid readily, however, and it was therefore placed in a slow stream of dry air and weighed at intervals of five minutes until the weight became constant. The resulting compound was the anhydrous monohydrochloride of tetrachlorgallein methyl ester, as shown by the following data:

Substance.	Gain in dry	Net gain after ex-	Hydrochloric
Gram.	HCl.	posure to air.	acid.
	Gram.	Gram.	Per cent.
0.2879	0.0340	0.0205	6.65
Calculated for $C_{20}H_7O_7Cl_4(CH_3).HCl$,			6.60

The properties and conduct of this compound were the same as those of the methyl ester hydrochloride made in benzene solution as described. When dissolved in ether, this hydrochloride is oxidized rapidly by the air, the solution becoming brownish yellow. The solid compound is more stable than tetrachlorgallein hydrochloride, as would be expected, since tetrachlorgallein is less basic than its methyl ester. In accord with this statement is the fact already mentioned that the methyl ester hydrochloride is formed by dissolving the methyl ester in aqueous hydrochloric acid (sp. gr. 1.10).

Tetrachlorgallein Ethyl Ester.

Twenty grams of pure anhydrous tetrachlorgallein were boiled for four hours with 200 grams of a three per cent. solution of hydrochloric acid in absolute ethyl alcohol, the crude ester precipitated with water, washed thoroughly, dried at room temperature, and purified by repeated crystallization from benzene. The product thus obtained contained benzene of crystallization and was therefore dried to constant weight in hydrogen at 157°. A chlorine determination in this dried material showed that it was the mono-ethyl ester of tetrachlorgallein.

Substance. Gram.	Tenth-normal silver nitrate. cc.	Chlorine. Per cent.
0.3141	23.75	26.81
Calculated for $C_{20}H_7O_7Cl_4(C_2H_5)$,		26.76

Further proof that this compound was really the *mono*-ethyl ester was furnished by an ethoxyl determination made by Mr. E. H. Nichols:

Substance. Gram.	Silver iodide. Gram.	C_2H_5O . Per cent.
0.3934	0.1465	7.14
Calculated for the mono-ethylester,		8.50

Hydriodic acid, sp. gr. 1.96, was used in this determination.

The ethyl ester of tetrachlorgallein resembles the methyl ester very closely in appearance, solubilities and conduct

toward reagents. It shows the same marked basic properties as the methyl ester, combining with hydrochloric acid gas and dissolving in hot aqueous hydrochloric acid (sp. gr. 1.10) with a deep red color. Crystallized from benzene and dried to constant weight at 157°, it melted with decomposition at 275°–280°, but showed a marked contraction and softening at about 230°.

This ethyl ester was also prepared by boiling a mixture of anhydrous tetrachlorgallein (10 grams), absolute ethyl alcohol (100 cc.) and concentrated sulphuric acid (20 grams) for three hours. The crude product was crystallized from benzene once and dried to constant weight at 157°. Analysis:

Substance. Gram.	Tenth-normal silver nitrate. cc.	Chlorine. Per cent.
0.1853	13.83	26.47
Calculated for the ethyl ester,		26.76

An attempt was also made to prepare the ethyl ester by boiling the monopotassium salt of tetrachlorgallein with a mixture of ethyl iodide and absolute alcohol in a flask connected with a return condenser, but no reaction took place even after five hours and so the attempt was abandoned.

Tetrachlorgallein Trimethyl Ether.

A filtered solution of 25 grams of anhydrous tetrachlorgallein in one liter of absolute methyl alcohol was heated to boiling in a flask connected with a return condenser through which was added 75 grams of pure methyl iodide and then a solution of sodium methylate made by dissolving 9 grams of sodium in 250 cc. of absolute methyl alcohol. The mixture was kept boiling vigorously throughout the experiment so that there was no danger of oxidation, the air being excluded by the vapors from the boiling liquid. After a half hour the color of the solution changed gradually from blue to purple and then to deep red. At the end of 20 hours the solution was still alkaline and hence 20 grams of methyl iodide were added and the boiling continued until the reaction was no longer alkaline, about six hours being required. The deep

red solution was then concentrated to 100 cc. and poured into two liters of ether. This ethereal solution contained a considerable amount of partially methylated products soluble in alkali with a red color and these were removed by repeated extraction with a one per cent. sodium hydroxide solution. The ethereal solution was then used in obtaining the tetramethyl ether described in the following pages (see page 249).

The red alkaline extracts were united and the resulting solution heated to boiling, filtered, and acidified with dilute hydrochloric acid. The faintly yellow curdy precipitate which separated was filtered off, washed thoroughly with water, dissolved in ether,¹ and the filtered ethereal solution concentrated. After several hours a large amount of pale yellow crystals separated and these were filtered off and recrystallized from 94 per cent. ethyl alcohol. The product thus obtained was perfectly white and melted at 253° – 254° (uncor.). Recrystallization from 80 per cent. methyl alcohol and from 50 per cent. acetone did not change this melting point and so it seemed likely that the compound was pure. It was dried to constant weight in carbon dioxide at 110° and analyzed for chlorine with the following results:

Substance. Gram.	Tenth-normal silver nitrate. cc.	Chlorine. Per cent.
0.2294	16.82	26.00
0.2189	16.11	26.10
Calculated for $C_{20}H_5O_7Cl_4(CH_3)_3$,		26.08
Calculated for $C_{20}H_6O_7Cl_4(CH_3)_2$,		26.76

The methoxyl content of this ether was determined by Mr. E. H. Nichols:

	Substance. Gram.	Silver iodide. Gram.	CH_3O . Per cent.
I	0.2985	0.4062	17.98
II	0.3196	0.4327	17.89
III	0.2882	0.3678	16.86
Calculated for the trimethyl ether,			17.11
Calculated for the dimethyl ether,			11.71

¹ Some of this product was insoluble in ether. It dissolved in one per cent. sodium hydroxide solution with a red color but the amount was too small to permit further investigation of the substance.

Nos. I and II were made with hydriodic acid of specific gravity 1.96 while III was made with the acid of specific gravity 1.7.

These analyses show clearly that the compound is the trimethyl ether of tetrachlorgallein. It is perfectly colorless and dissolves in ether, benzene and chloroform without color, while solutions in alcohol or acetone have a faint pink color. Like the trimethyl ether of gallein it resembles phenolphthalein very closely. It possesses fairly strong acid properties, reacting with sodium carbonate as well as with sodium hydroxide to form a sodium salt soluble in water with a red color.

Sodium and Ammonium Salts of the Trimethyl Ether of Tetrachlorgallein.

For the isolation of this sodium salt the following method was employed: An alcoholic solution of sodium hydroxide was added to a boiling alcoholic solution of the trimethyl ether, the proportions adopted being such that there was an excess of the trimethyl ether. The resulting deep red solution was then diluted with ether and the dark red precipitate formed filtered off, washed with ether, and dried to constant weight in hydrogen at 157°. The sodium in this salt was determined by decomposing a weighed portion of the substance with a measured excess of tenth-normal hydrochloric acid, filtering off the precipitated trimethyl ether, and titrating the excess of acid in the filtrate with tenth-normal sodium hydroxide solution, the trimethyl ether which remained in solution acting as the indicator.

Substance. Gram.	Tenth-normal hydrochloric acid. cc.	Sodium. Per cent.
0.4190	8.30	4.55
0.4634	8.80	4.37
Calculated for $C_{20}H_4O_7Cl_4(CH_3)_3Na$,		4.06

This sodium salt has a brick-red color and dissolves readily in water, alcohol and acetone with a red color, but is insoluble in ether, chloroform and benzene. When the red aqueous solution is acidified with hydrochloric acid, the color-

less trimethyl ether is precipitated. In one respect the trimethyl ether of tetrachlorgallein differs very markedly from phenolphthalein. Its dilute alkaline solution is not decolorized by the addition of strong alkalies or of alcohol. Indeed alcohol increases the color of such a solution. For this reason it may be used as an indicator for titrating alcoholic solutions. An excess of alkali or alkaline carbonates precipitates the sodium salt as an amorphous product resembling ferric hydroxide.

Further proof of the acid character of tetrachlorgallein trimethyl ether is found in its conduct toward dry ammonia gas. A weighed portion of the *colorless* trimethyl ether was placed in a current of ammonia gas carefully dried with soda-lime. It turned pink at once and came to constant weight after two hours, taking up exactly one molecule of ammonia, as shown by the following data:

Trimethyl ether. Gram.	Gain. Gram.	Ammonium salt of trimethyl ether. Gram.	Ammonia. Per cent.
0.1856	0.0055	0.1911	2.88
Calculated for $C_{20}H_5O_7Cl_4(CH_3)_3.NH_3$,			3.04

This *red* trimethyl ether monammonium salt was then placed in a current of air dried with calcium chloride. It lost ammonia slowly but completely, yielding the original weight of the *colorless* trimethyl ether.

Tetrachlorgallein Trimethyl Ether Hydrochloride.

Although tetrachlorgallein trimethyl ether has acid properties, yet it is also somewhat basic. It does not dissolve in hot aqueous hydrochloric acid (sp. gr. 1.10), but it does react with dry hydrochloric acid gas and forms a red hydrochloride showing a dull greenish luster. The amount of hydrochloric acid absorbed is a little greater than that calculated for one molecule, as shown in the following table:

Trimethyl ether. Gram.	Gain. Gram.	Trimethyl ether hydrochloride. Gram.	Hydrochloric acid. Per cent.
0.1636	0.0125	0.1761	7.10
Calculated for $C_{20}H_5O_7Cl_4(CH_3)_3.HCl$,			6.44

Nevertheless it is evident that a monohydrochloride is formed as with tetrachlorgallein itself and with its methyl

ester. The *red* trimethyl ether hydrochloride is perfectly stable in dry air at room temperature, but at 157° it is decomposed quantitatively into hydrochloric acid and the *colorless* trimethyl ether.

A method of making the trimethyl ether which is better than the one already described consists in cautiously adding dimethyl sulphate to a boiling solution of tetrachlorgallein in 2 per cent. alcoholic sodium hydroxide solution, oxidation being prevented by keeping the flask filled with hydrogen. The reaction is complete in about one hour and the yield of trimethyl ether is excellent. Its separation is accomplished as described in the case of the ether made from methyl iodide and an alkaline alcoholic solution of tetrachlorgallein.¹

Tetrachlorgallein Trimethyl Ether Monacetate.

Although the trimethyl ether of tetrachlorgallein acts like a fairly strong acid, decomposing carbonates and combining with ammonia, still it seemed likely that it would react with acetic anhydride to form an acetate analogous to gallein trimethyl ether monacetate.² A mixture of 5 grams of pure trimethyl ether, 5 grams of sodium acetate and 25 grams of acetic anhydride was boiled for thirty minutes, when acetylation was complete, as shown by the fact that a test drop no longer gave a red color with sodium hydroxide solution. When this reaction mixture was poured into cold water, a brown oil separated which solidified after a short time to a yellow crystalline mass. This crude acetate was filtered off, washed with water, and crystallized from 80 per cent. alcohol. The product obtained in this manner was colorless and melted sharply at 221° (uncor.). It was dried to constant weight in carbon dioxide at 110° and analyzed for chlorine:

Substance. Gram.	Tenth-normal silver nitrate. cc.	Chlorine. Per cent.
0.2113	14.30	24.00
0.2168	14.68	24.01
Calculated for $C_{20}H_4O_7Cl_4(CH_3)_3(C_2H_3O)$,		24.21

¹ Page 245.

² Orndorff and Brewer: *THIS JOURNAL*, 26, 136.

The properties of this compound are also in accord with the above formula. It is insoluble in cold aqueous alkalis, but boiling caustic soda solution dissolves it gradually with the red color characteristic of the trimethyl ether dissolved in alkali. In order to show that this acetate is really saponified, with the formation of the trimethyl ether, a small portion was boiled for two hours with a 2 per cent. solution of sodium hydroxide in methyl alcohol. The resulting solution was poured into cold water, an excess of hydrochloric acid added, and the pink precipitate formed was filtered off, washed with water, and crystallized from 80 per cent. alcohol. Colorless crystals were thus obtained which melted at 252° – 254° (uncor.), and had the other properties of the trimethyl ether. They were dried to constant weight in carbon dioxide at 110° and analyzed:

Substance. Gram.	Tenth-normal silver nitrate. cc.	Chlorine. Per cent.
0.2183	16.05	26.07
Calculated for the trimethyl ether,		26.08

Hence the tetrachlorgallein trimethyl ether monacetate is saponified by alkalis with the formation of the trimethyl ether.

Tetrachlorgallein Tetramethyl Ether (Colored).

The deep red ethereal solution from which the tetrachlorgallein trimethyl ether had been extracted with dilute sodium hydroxide solution¹ was thoroughly washed with water, filtered twice, and concentrated to a small volume. Dark red crystals formed gradually, and after about twenty hours these were filtered off, washed with ether, and recrystallized from ether. The crystals thus obtained melted at 217° (uncor.), and were red in transmitted light but dark green by reflected light. When this product was powdered by grinding, it lost the green color completely, and was then red by reflected as well as transmitted light. Chlorine and methoxyl determinations on this material, dried to constant weight at

¹ Page 245.

110°, showed that it was a tetramethyl ether of tetrachlorgallein:

Substance. Gram.	Tenth-normal silver nitrate. cc.	Chlorine. Per cent.
0.2779	19.83	25.30
0.1953	13.99	25.40
Calculated for $C_{20}H_4O_7Cl_4(CH_3)_4$,		25.42
Calculated for $C_{20}H_5O_7Cl_4(CH_3)_3$,		26.08

Methoxyl determinations made by Mr. E. H. Nichols gave the following results:

	Wt. substance.	Wt. AgI.	CH ₃ O. Per cent.
I	0.2884	0.4943	22.65
II	0.3009	0.5110	22.44
Calculated for the trimethyl ether,			17.11
Calculated for the tetramethyl ether,			22.24

This red tetrachlorgallein tetramethyl ether is insoluble in water and in cold aqueous sodium hydroxide solution, but boiling aqueous alkali saponifies and dissolves it slowly with a red color. It dissolves readily with a red color in alcohol, ether, acetone, benzene, ethyl acetate and chloroform. The crystals from ether were examined by Professor A. C. Gill, of the Mineralogical Department of Cornell University, and his report is as follows:

"The crystals are either triclinic or monoclinic, probably the latter, since many show parallel extinction. Optical angle is small, pleochroism rather strong—deep red to yellowish red—and double refraction fairly high. The habitus of the crystals is stout columnar."

The fact that the tetrachlorgallein tetramethyl ether has a marked red color indicates that it is a quinoid compound and therefore similar in structure to the methyl and ethyl esters of tetrachlorgallein. Hence it seemed likely that the solubility of the red tetramethyl ether in hot alkali was due to saponification of the compound. To test the correctness of this view 2 grams of the pure red tetramethyl ether were boiled for two hours with 200 cc. of a 2 per cent. solution of sodium hydroxide in absolute methyl alcohol. The red

solution was diluted with water and acidified with hydrochloric acid. A faintly yellow precipitate was thrown down and the solution became colorless. This yellow precipitate was filtered off, washed with water, and crystallized from dilute alcohol. The resulting product was white, melted sharply at 253° – 254° (uncor.), dissolved in alkali with a red color, and showed all the other properties of the colorless tetrachlorgallein trimethyl ether already described.¹ Analysis of this material dried to constant weight in hydrogen at 156° showed that it is really the tetrachlorgallein trimethyl ether:

Substance. Gram.	Tenth-normal silver nitrate. cc.	Chlorine. Per cent.
0.2611	19.16	26.02
Calculated for the trimethyl ether,		26.08

Hence the red tetramethyl ether of tetrachlorgallein is really the monomethyl ester of the trimethyl ether. This was further shown by making the red tetramethyl ether by boiling the colorless trimethyl ether of tetrachlorgallein with a 3 per cent. solution of hydrochloric acid in absolute methyl alcohol.

The red tetrachlorgallein tetramethyl ether, like the tetrachlorgallein methyl ester of which it is a derivative, possesses basic properties. It dissolves in hot hydrochloric acid solution (sp. gr. 1.1) with a deep red color, and when the solid ether is exposed to the action of dry hydrochloric acid gas a red hydrochloride is formed. The amount of hydrochloric acid gas absorbed was much greater than that required for a monohydrochloride, but when this material was left in a current of dry air until it came to constant weight, the resulting product was the monohydrochloride of tetrachlorgallein tetramethyl ether, as shown by the following data:

Tetramethyl ether. Gram.	Net gain. Gram.	Tetramethyl ether hydrochloride. Gram.	Hydrochloric acid. Per cent.
0.4779	0.0319	0.5098	6.26
Calculated for $C_{20}H_4O_7Cl_4(CH_3)_4.HCl$,			6.14

¹ Page 244.

This hydrochloride is fairly stable in the air but is decomposed by hot water with the formation of hydrochloric acid and tetrachlorgallein tetramethyl ether.

Orndorff and Brewer¹ obtained not only a *colored* tetramethyl ether of *gallein*, but also a small amount of a *colorless* tetramethyl ether. Tetrachlorgallein, however, gave only the colored tetramethyl ether described above. It seemed likely that this colored tetramethyl ether might be transformed into a colorless tetramethyl ether by heating with solvents. Accordingly a solution of 2 grams of the red tetramethyl ether in 200 cc. of 70 per cent. ethyl alcohol was boiled for forty hours and then allowed to cool. The crystals which separated were examined under the microscope, and while there were a few stout columnar crystals of the red tetramethyl ether, still most of the material consisted of minute, almost *colorless* needles exactly like the crystals of the colorless gallein tetramethyl ether described by Orndorff and Brewer. These crystals were not soluble in boiling aqueous alkali nor were they saponified by alcoholic caustic soda, and hence could not have been either the tetrachlorgallein trimethyl ether or the red tetramethyl ether. The amount of material was entirely too small for an analysis but there can be no doubt, from the properties of the compound, that it was the *colorless* tetramethyl ether of tetrachlorgallein.

It is very likely that an alkaline solution of *gallein* also yields only the colored tetramethyl ether with methyl iodide and that the colorless tetramethyl ether obtained by Orndorff and Brewer resulted from a molecular rearrangement of the colored tetramethyl ether, especially as they purified this compound by crystallization from 50 per cent. alcohol and boiled the solution for some time with boneblack. In the case of tetrachlorgallein, there is no evidence of the formation of a colorless tetramethyl ether with methyl iodide or with dimethyl sulphate.

Tetrachlorgallein Dimethyl Ether Diacetate.

In one of the first attempts to make the tetrachlorgallein

¹ THIS JOURNAL, 26, 138.

tetramethyl ether by alkylation with methyl iodide, a white product was obtained which melted with decomposition at 253° – 258° (uncor.). This material could not be purified by crystallization and so it was converted into an acetate by boiling with acetic anhydride and sodium acetate. The crude acetate was purified by crystallization from alcohol, dried to constant weight at 110° , and analyzed for chlorine:

Substance. Gram.	Tenth-normal silver nitrate. cc.	Chlorine. Per cent.
0.2345	15.49	23.39
0.2327	15.30	23.29
Calculated for $C_{20}H_4O_7Cl_4(CH_3)_2(C_2H_5O)_2$,		23.11

This compound is therefore the diacetate of a tetrachlorgallein dimethyl ether and its properties are in accord with this view. It is colorless, melts at 225° (uncor.), and is insoluble in cold caustic alkali though it dissolves in hot alkali, imparting a red color to the solution as saponification proceeds.

THEORETICAL.

The formula given to tetrachlorgallein by Graebe¹ is $C_{20}H_6O_7Cl_4$. In support of this formula he gives two analyses of the product precipitated from alcoholic solution by water and dried at 100° , and one analysis of this compound dried at 180° . From his analyses of the compound dried at 100° he deduces the formula $C_{20}H_6O_7Cl_4 \cdot 2H_2O$, and for the product dried at 180° the formula $C_{20}H_6O_7Cl_4$. Graebe determined only carbon and hydrogen in his tetrachlorgallein, and as he probably dried the compound in air it was undoubtedly oxidized and impure. It is impossible, moreover, to decide between Graebe's formula and the formula $C_{20}H_8O_7Cl_4$ by determining carbon and hydrogen only. This is clearly shown in the following table:

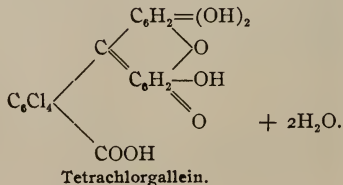
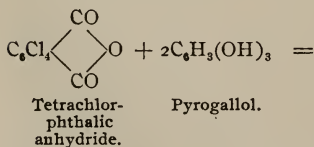
	Calculated for $C_{20}H_6O_7Cl_4$. Per cent.	Calculated for $C_{20}H_8O_7Cl_4$. Per cent.	Found by Graebe. Per cent.
Carbon.....	48.01	47.82	48.41
Hydrogen.....	1.21	1.61	1.89

¹ Ann. Chem. (Liebig), **238**, 337 (1881).

It is quite evident, therefore, that in assigning the above formula to tetrachlorgallein, Graebe simply took the formula for gallein, $C_{20}H_{10}O_7$, given by Buchka,¹ and substituted four chlorine atoms for four of the hydrogen atoms. This is also shown in Graebe's formula for the acetate, $C_{26}H_4O_7Cl_4(C_2H_3O)_4$, which is plainly derived from Buchka's formula for gallein tetracetate, $C_{20}H_8O_7(C_2H_3O)_4$, in the same way. Moreover, the percentages of carbon, hydrogen and chlorine found by Graebe for this acetate do not agree at all well with those required by the above formula.

The work of Orndorff and Brewer,² however, has shown that the formula given by Buchka for gallein is not correct and establishes the formula $C_{20}H_{12}O_7$ for this compound. The present investigation proves that tetrachlorgallein has the formula $C_{20}H_8O_7Cl_4$, and hence confirms the formula for gallein given by Orndorff and Brewer. It also proves that the formula for the hydrate is not $C_{20}H_6O_7Cl_4 \cdot 2H_2O$, as given by Graebe, but $C_{20}H_8O_7Cl_4 \cdot H_2O$, analogous to that of gallein hydrate, $C_{20}H_{12}O_7 \cdot H_2O$. The formula $C_{20}H_8O_7Cl_4$ is the logical one to assign to tetrachlorgallein from its analogy to fluorescein, both as to its properties and the method by which it is prepared.

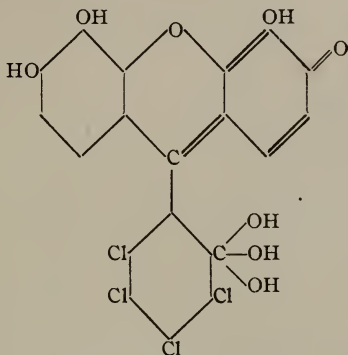
The formation of tetrachlorgallein may be represented by the following equation:



¹ Ann. Chem. (Liebig), **209**, 251.

² THIS JOURNAL, **26**, 97 (1901).

The crude product obtained after removal of the zinc chloride is the monohydrate, and the same compound results from the metallic salts of tetrachlorgallein when they are decomposed with acids. As this hydrate is a *colored* compound which decomposes carbonates and acetates to form salts and combines with alcohols to form esters, it probably is a quinoid compound as well as an acid and must therefore be represented by the structural formula

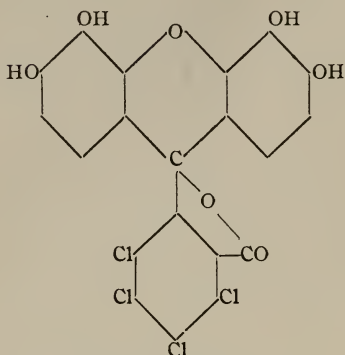


Tetrachlorgallein monohydrate.

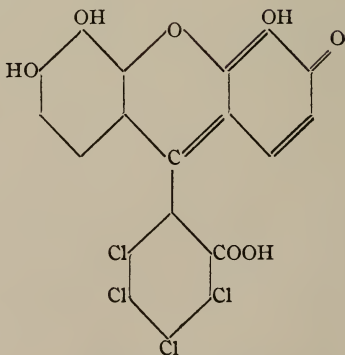
The extra molecule of water which the compound contains is here represented as water of constitution rather than as water of crystallization for the reason that it cannot be driven off completely until a temperature of 157° is reached and because tetrachlorphthalic acid itself contains a half molecule of water which must be regarded as water of constitution. In this connection it may be well to note that both the monosodium and monopotassium salts persistently retain a half molecule of water until they are heated to 157° .

The anhydrous tetrachlorgallein made from the monohydrate and also from the crude product crystallized from methyl alcohol, by heating to 157° , has only a faint pink color and therefore is the lactoid form of tetrachlorgallein

(I), or at any rate a mixture of this form with a small amount of the quinoid modification (II).



I. Lactoid form, colorless.



II. Quinoid form, colored.

Tetrachlorgallein.

Derivatives of both these tautomeric modifications have been made and analyzed. The tetrachlorgallein tetracetate,

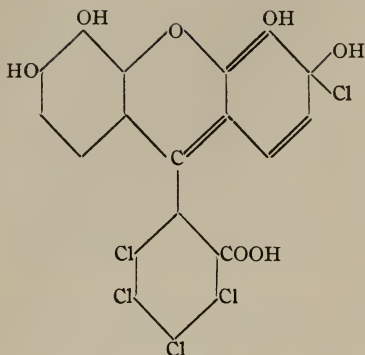
tetraphenylcarbamate, the tetramethyl ether not saponified by alkalies, the trimethyl ether and its acetate, are all colorless compounds and must hence be derivatives of the lactoid form (I). The metallic and ammonium salts, the esters and their hydrochlorides, the tetramethyl ether saponified by alkalies and its hydrochloride, the sodium and ammonium salts and the hydrochloride of the colorless trimethyl ether, the hydrochloride and the monohydrate of tetrachlorgallein itself, are all highly colored compounds and must therefore be regarded as derived from the quinoid form of tetrachlorgallein (II).

Tetrachlorgallein is then completely analogous to gallein. Gallein itself, according to Heller and Langkopf,¹ forms a hydrate, $C_{26}H_{12}O_7 \cdot H_2O$, having a reddish brown color, and as this substance does not lose its water completely until 180° and acts as an acid, it seems probable that it has a structure like that assigned to tetrachlorgallein hydrate.²

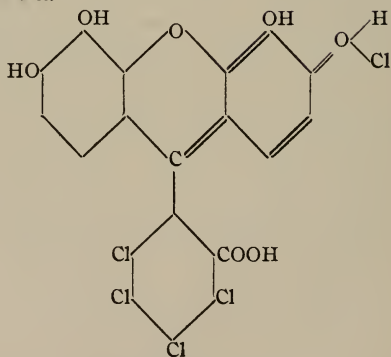
The introduction of the four chlorine atoms into the phthalic acid residue of gallein increases its acid and decreases its basic properties. That is, tetrachlorgallein is a stronger acid and a weaker base than gallein. This is shown very clearly by the fact that gallein itself dissolves readily in hot aqueous hydrochloric acid (sp. gr. 1.10) and the hydrochloride crystallizes from the filtrate, while tetrachlorgallein is insoluble in this hydrochloric acid and a hydrochloride cannot be obtained under these conditions. Tetrachlorgallein still possesses basic properties, however, since it forms a red hydrochloride when brought into contact, in the solid state or in solution in acetone, with dry hydrochloric acid gas. The esters of tetrachlorgallein, the colored tetramethyl ether (which is really a methyl ester of the trimethyl ether) and the colorless trimethyl ether also form red hydrochlorides very readily. These hydrochlorides may be regarded either as carbonium or oxonium salts, as shown in the formulas (I) and (II):

¹ Z. Farb. Ind., 5, 115; Inaugural Dissertation, Ueber Mineral Salze der Phthaleinreihe, 30.

² Page 255.



I. Carbonium salt.

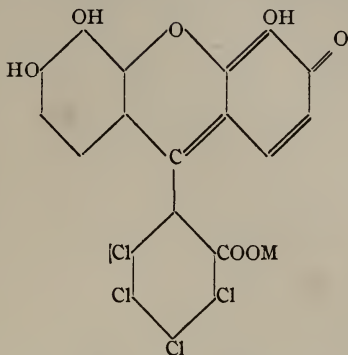


II. Oxonium salt.

Tetrachlorgallein hydrochloride.

It is interesting to note that the methyl and ethyl esters of tetrachlorgallein dissolve in hot aqueous hydrochloric acid (sp. gr. 1.10) and the hydrochlorides may be obtained from the filtrate in crystalline form.

The structural formulas of the monosodium and monopotassium salts and of the methyl and ethyl esters are represented as follows:



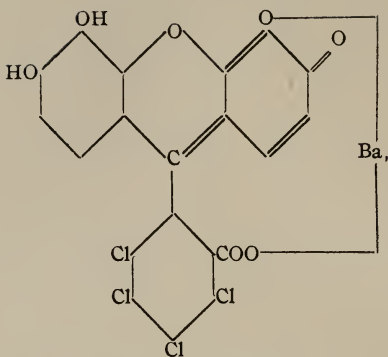
Alkali salts and esters of tetrachlorgallein.
(M represents Na, K, CH₃ or C₂H₅.)

The fact that tetrachlorgallein forms esters so readily by the ordinary catalytic method of esterification is worthy of note, since it forms an exception to the Victor Meyer rule¹ that substituents in both positions ortho to the carboxyl group inhibit the formation of esters by the ordinary catalytic method. The trimethyl ether of tetrachlorgallein also forms an ester by the ordinary method of esterification. In this respect tetrachlorgallein differs from its isomer, oxyhydroquinonetetrachlorphthalein, which, according to Osorovitz,² does not form an ester by the catalytic method.

In the barium salt there is present one atom of barium to four atoms of chlorine, and hence two of the hydrogen atoms (one in the carboxyl group and one in one of the hydroxyl groups) must be replaced by barium. As the hydroxyl group in the quinoid ring would probably be more acid than the other hydroxyl groups, the barium salt would probably have the structure

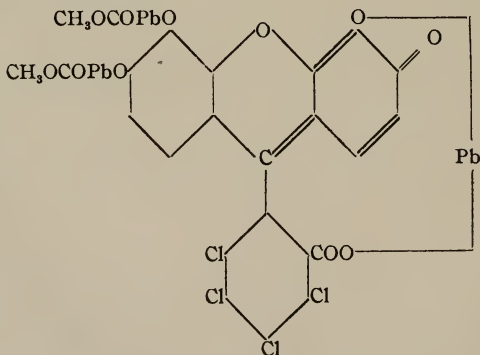
¹ Ber. d. chem. Ges., **27**, 510, 1580 and 3146. See also Rosanoff and Prager: J. Am. Chem. Soc., **30**, 1895.

² Ber. d. chem. Ges., **36**, 1076 (1903).



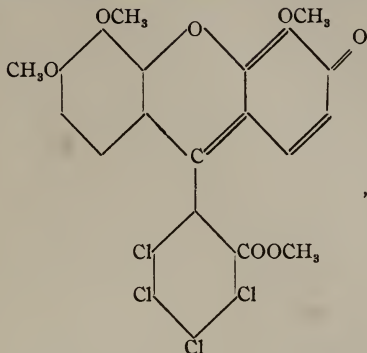
Barium salt of tetrachlorgallein.

and for the same reason the complex lead salt would have a similar formula:



Lead salt of tetrachlorgallein.

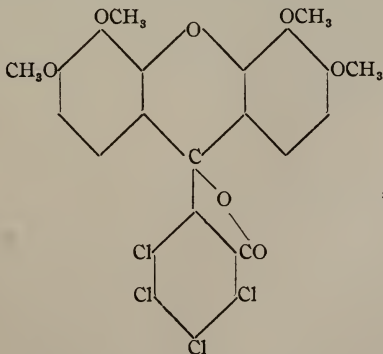
The red tetramethyl ether made by the action of methyl iodide or dimethyl sulphate on an alkaline solution of tetrachlorgallein, like the red tetramethyl ether of gallein, must have the quinoid structure as shown in the formula



Tetrachlorgallein tetramethyl ether (colored).

first, on account of its color; secondly, because, when saponified with alcoholic caustic soda, it yields the colorless trimethyl ether; and thirdly, because it can be made from the colorless trimethyl ether by the ordinary process of esterification.

The colorless tetramethyl ether which is formed from the above compound by simply boiling its alcoholic solution for a sufficient length of time, must have the lactoid structure



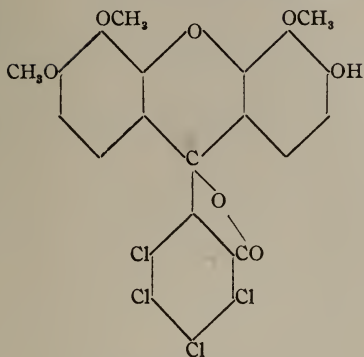
Tetrachlorgallein tetramethyl ether (colorless).

since it is insoluble in aqueous alkalies, has no color, and is not saponified by alcoholic caustic soda. The transformation of the colored into the colorless ether is strictly analogous to that observed in the case of the diethyl ether of phenolphthalein and of tetrabromphenolphthalein by R. Meyer and Marx,¹ though the change here takes place much less readily than in the cases mentioned by these authors. This easy change of the colored over into the colorless ethers by simply heating their solutions explains in a very satisfactory manner why in many cases the colorless ethers alone are obtained under conditions when the colored ethers are naturally to be expected, and also probably explains why Orndorff and Brewer² got both the colored and colorless tetra-ethers of gallein when they heated an alkaline solution of this substance in alcohol for a long time with an excess of methyl iodide. It seems highly probable, indeed, that colored ethers are first formed in all cases and then undergo molecular rearrangement into the colorless compounds.

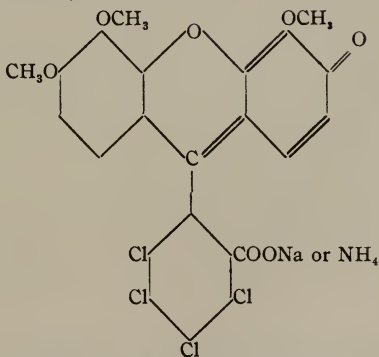
The trimethyl ether prepared from tetrachlorgallein itself or from the colored tetramethyl ether by saponification is *colorless* and exactly analogous to the trimethyl ether of gallein, and hence the lactoid formula (I) is assigned to it, while the quinoid formula (II) best represents the structure of its red sodium and ammonium salts and shows the analogy of these salts to the red tetramethyl ether (see page 261):

¹ Ber. d. chem. Ges., **40**, 1437, 3603 (1907), and **41**, 2446 (1908).

² THIS JOURNAL, **26**, 137 (1901).



I. Trimethyl ether of tetrachlorgallein (colorless).

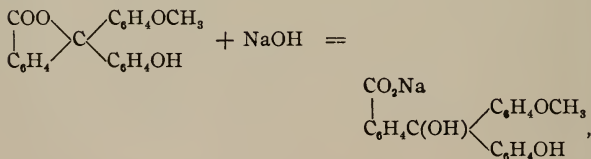


II. Sodium and ammonium salts of tetrachlorgallein trimethyl ether (colored).

The trimethyl ether is then tautomeric and resembles phenolphthalein very closely indeed. It reacts as an indicator exactly as phenolphthalein does. It yields a *colorless* monoacetate and monomethyl ether (the colorless tetramethyl ether of tetrachlorgallein, see page 261), which must hence have the lactoid structure, and *colored* sodium and ammonium

salts (see II above), as well as a *colored* monomethyl ester (the colored tetramethyl ether of tetrachlorgallein, see page 261) having the quinoid structure.

The fact that this colorless trimethyl ether forms colored salts and esters in exactly the same way that phenolphthalein does seems to be an insuperable objection to the oscillation theory recently advanced by Baeyer as an explanation of the color of the aniline and aurin dyestuffs (see page 205) and is in accord with the observation of Orndorff and Black¹ that the colorless monomethyl ether of phenoltetrachlorphthalein dissolves in alkalis with a red color. If this observation of Orndorff and Black should be confirmed it would form a further objection to Baeyer's oscillation theory mentioned above. The colorless monomethyl ether of phenolphthalein also dissolves in alkalis with a red color, according to R. Meyer and Spengler,² though this statement is disputed by Green and King,³ who attribute the color to the presence of a small amount of phenolphthalein in the methyl ether. They are of the opinion that the ether is directly converted by alkalis into the colorless carbinol salt, as shown in the equation



and they cite the case of the colorless monomethyl ether of tetrabromphenolphthalein, which, according to Nietzki and Burckhardt,⁴ also dissolves in dilute caustic alkalis without color. If these observations of Green and King and of Nietzki and Burckhardt should be substantiated they may be regarded as supporting Baeyer's theory of color, since there is no possi-

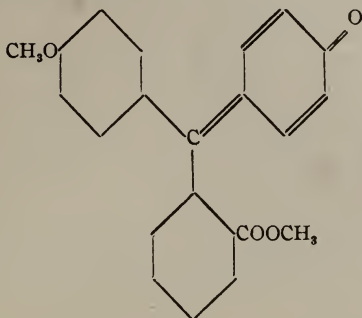
¹ THIS JOURNAL, **41**, 377 (1909).

² Ber. d. chem. Ges., **38**, 1318 (1905).

³ J. Soc. Chem. Ind., **27**, 6 (1908).

⁴ Ber. d. chem. Ges., **30**, 178 (1897).

bility here of oscillation. Even granting this, however, the theory is not capable of explaining the color of such compounds as the methyl ester of phenolphthalein methyl ether made by Green and King,



or the colored diethyl ethers of phenolphthalein and of tetrabromphenolphthalein made by R. Meyer and Marx¹ unless it be assumed that the alkyl radicals can oscillate in the same manner as the metals. The colored tetramethyl ether of oxyhydroquinonetetrachlorophthalein² and the colored tetramethyl and tetraethyl ethers of gallein,³ as well as the colored dialkyl ethers of fluorescein and eosin, are further examples of colored compounds which cannot be explained by Baeyer's theory.

It may be well to emphasize here the interesting fact that the *colorless* trimethyl ether in the *solid state* takes up exactly one molecule of ammonia when placed in a current of dry ammonia gas and is converted into the *colored* monammonium salt. This salt loses all of its ammonia when placed in a current of dry air, leaving the colorless trimethyl ether unchanged (see page 247). This observation is similar to that made by Orndorff and Black⁴ in the case of tetrabromphenol-

¹ Ber. d. chem. Ges., **40**, 1437, 3603 and **41**, 2446.

² Osorovitz: Ber. d. chem. Ges., **36**, 1076.

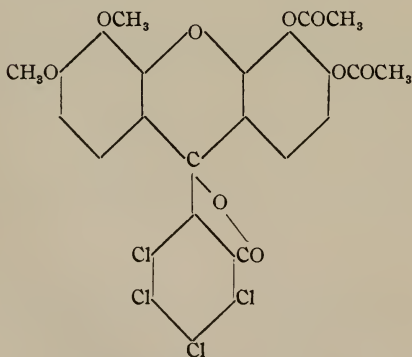
³ Orndorff and Brewer: *THIS JOURNAL*, **26**, 97.

⁴ *THIS JOURNAL*, **41**, 384 (1909).

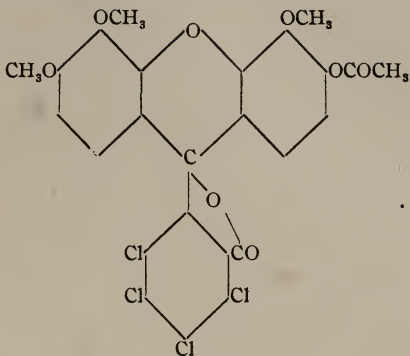
tetrachlorphthalein, which is *colorless* and in the *solid state* absorbs two molecules of ammonia to form the *blue* diammonium salt. On standing in the air this *blue* salt loses all of its ammonia and is transformed back again into the *colorless* phthalein. It is necessary, therefore, to assume that the change from the lactoid to the quinoid form and back again can take place in *solids* as well as in solution.

A similar change takes place when the *colorless* trimethyl ether of tetrachlorgallein in the *solid state* takes up hydrochloric acid gas, forming the *red* hydrochloride which loses all the hydrochloric acid when heated, thus yielding the *colorless* trimethyl ether again (see page 247).

The tetrachlorgallein dimethyl ether diacetate is also a colorless compound and must have the lactoid structure like the colorless trimethyl ether monacetate, as shown in the formulas

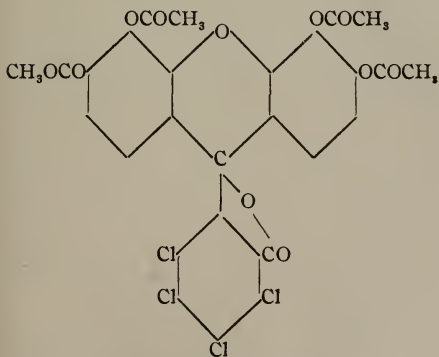


Tetrachlorgallein dimethyl ether
diacetate.

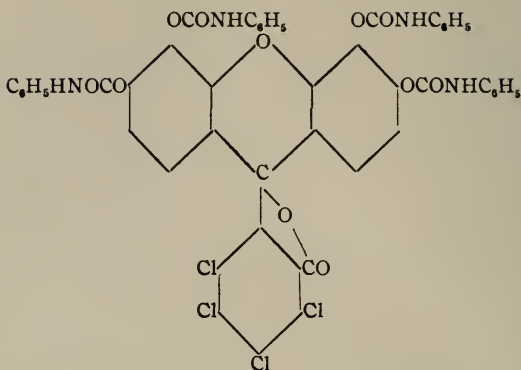


**Tetrachlorgallein trimethyl
ether monacetate.**

The tetracetate and tetraphenylcarbamate are also colorless compounds and must hence be represented by the following lactoid formulas:



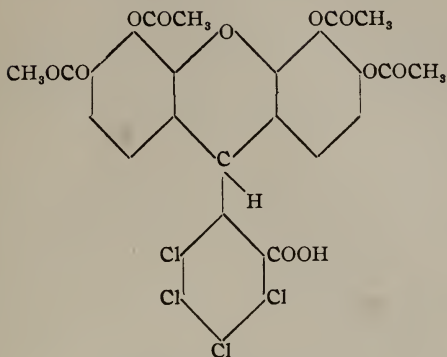
Tetrachlorgallein tetracetate.



Tetrachlorgallein tetraphenylcarbamate.

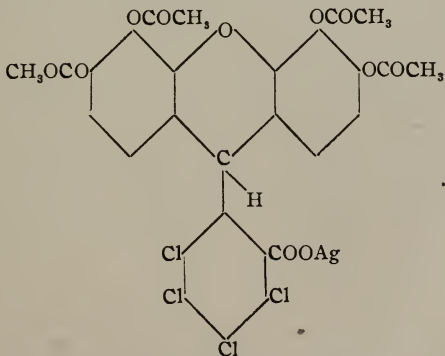
Orndorff and Brewer state that gallein forms a colored triphenylcarbamate. As they purified their compound by precipitation and determined the nitrogen by the Kjeldahl method, which in the case of the tetrachlorgallein compound was found not to give concordant results (see page 236), it is probable that this product was really a tetraphenylcarbamate. The color of the compound was light yellow and from the method of purifying it this may well have been due to the impurities. This is the only important point in which the results obtained by Orndorff and Brewer on gallein differ from those obtained on tetrachlorgallein, and as it seems highly probable that both substances would act exactly alike toward phenyl isocyanate and in the same manner as they do toward acetic anhydride, it is quite likely that a repetition of this work on gallein phenylcarbamate, by the same method as that used in making the tetrachlorgallein compound, would give a colorless tetraphenylcarbamate.

Tetrachlorgallin tetracetate results from the tetrachlorgallein tetracetate by the addition of two atoms of hydrogen and as it is a colorless compound and also an acid it must have the following structure:



Tetrachlorgallein tetracetate.

In accord with this formula is the fact that the substance dissolves in sodium carbonate solution, setting free carbon dioxide, and also forms a crystalline stable silver salt,



Silver salt of tetrachlorgallein tetracetate.

The existence of these two substances establishes the presence of four phenol hydroxyl groups and one carboxyl group in the molecule of tetrachlorgallein and confirms the formula for gallin established by Orndorff and Brewer.

SUMMARY.

The results of this investigation may be briefly stated as follows:

(1) Tetrachlorgallein is completely analogous to gallein. Its formula is $C_{20}H_8O_7Cl_4$ and that of its hydrate is $C_{20}H_8O_7Cl_4 \cdot H_2O$.

(2) Tetrachlorgallein contains a carboxyl group as is shown by its forming ammonium, sodium, potassium, barium and lead salts and methyl and ethyl esters. These compounds are all colored and must therefore have the quinoid structure. Tetrachlorgallein hydrate is also a colored substance and is hence to be represented as a quinoid compound. The anhydrous tetrachlorgallein, on the other hand, is so slightly colored that it probably has the lactoid structure or is a mixture of the lactoid compound with a small amount of the quinoid modification.

(3) The formation of a colored tetramethyl ether which, on saponification, yields a colorless trimethyl ether indicates the presence of three phenol hydroxyl groups and a carboxyl group in the molecule of tetrachlorgallein.

(4) Tetrachlorgallein, like gallein, is a tautomeric compound. In addition to the above-mentioned colored derivatives having the quinoid structure, it gives colorless compounds such as the tetracetate, the tetraphenylcarbamate, the colorless tetramethyl ether, the trimethyl ether and its acetate and the dimethyl ether diacetate, to which the lactoid formula must be assigned. The formation of these compounds indicates the presence of four phenol hydroxyl groups in the lactoid modification of tetrachlorgallein.

(5) A colorless trimethyl ether of tetrachlorgallein has been made. This substance is also tautomeric. It yields a colorless monacetate and monomethyl ether, and colored sodium and ammonium salts, as well as a colored methyl ester. The formation of these colored substances seems an insuperable objection to Baeyer's oscillation theory of the cause of color in the aniline and aurin dyes. The colorless trimethyl ether in the *solid state* combines with both ammonia and with hydrochloric acid to form *colored* compounds which

revert to the colorless ether in the air or on heating. This necessitates the assumption that the transformation from the lactoid into the quinoid condition and back again can take place in *solids* as well as in solution.

(6) Tetrachlorgallein is basic as well as acid, though not so basic as gallein itself. It combines with hydrochloric acid to form a red hydrochloride, and its esters (including the colored tetramethyl ether), as well as the colorless trimethyl ether, combine even more readily with this acid.

(7) Reduction of tetrachlorgallein tetracetate with nascent hydrogen yields the colorless tetrachlorgallin tetracetate, which has acid properties and gives a silver salt. Hence tetrachlorgallin must contain four phenol hydroxyl groups and one carboxyl group. This work confirms the formula for gallin established by Orndorff and Brewer.

(8) Tetrachlorgallein and its trimethyl ether form esters by the ordinary catalytic method of esterification and hence are exceptions to the Victor Meyer rule that compounds containing two substituents ortho to a carboxyl group do not form esters by the catalytic method or only form them with great difficulty. In this respect tetrachlorgallein differs markedly from its isomer, oxyhydroquinonetetrachlorphthalein, which, according to Osorovitz, does not form an ester by the catalytic method.

Another paper on tetrachlorgallein will be published in THIS JOURNAL in the near future.

CORNELL UNIVERSITY,
June, 1909.

[Contributions from the Sheffield Laboratory of Yale University.]

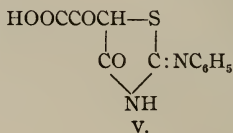
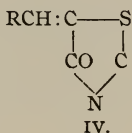
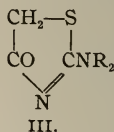
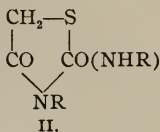
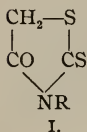
CLXIX.—RESEARCHES ON PYRIMIDINES:
SULPHUR DERIVATIVES OF 5-HYDROXYURACIL:
PREPARATION OF 5-BENZYL MERCAPTLOURACIL
AND 5-BENZYL MERCAPTOCYTOSINE.

[FORTY-FIFTH PAPER.]

BY TREAT B. JOHNSON AND HERBERT H. GUEST.

Several investigators have shown that the methylene hydrogens of cyclic compounds which contain the $\text{—S—CH}_2\text{—CO—}$

grouping—rhodanic acids¹ (I) and pseudothiohydantoins² (II) and (III)—react with aldehydes, in presence of alkali, giving unsaturated condensation products (IV). It has also



been shown that the methylene group of arylpseudothiohydantoins is capable of condensing with diethyl oxalate in presence of sodium ethylate. Wheeler and Jamison,³ for example, prepared in this manner phenylpseudothiohydantoinglyoxylic acid (V), from stable phenylpseudothiohydantoin. Loven⁴ examined the behavior of the methylene groups in thiodiglycollic acid towards benzaldehyde and obtained the sulphide of α -mercaptocinnamic acid, $(\text{C}_6\text{H}_5\text{CH:CCOOH})_2\text{S}$, but no attempts, so far as the writer is aware,⁵ have been made to condense ethyl formate or diethyl oxalate with any acyclic compound containing the grouping $\text{—S—CH}_2\text{—CO—}$.

A search of the literature⁶ reveals the fact that no α - or

¹ Nencki: Ber. d. chem. Ges., **17**, 2278 (1884). Giesberg and Bondzynski: *Ibid.*, **19**, 113 (1886). Bondzynski: Monats. Chem., **8**, 349 (1887). Zipser: *Ibid.*, **23**, 958; Centralb., **1903**, I, 283. Andreasch and Zipser: Monats. Chem., **24**, 499; **25**, 159; **26**, 1191; Chem. Ztg., **26**, 54, 623. Stuchetz: Monats. Chem., **26**, 1209. Andreasch: *Ibid.*, **27**, 1211. Wagner: *Ibid.*, **27**, 1223. Bargellini: Atti. Accad. Lincei, [5] **15**, I, 35, 181; Centralb., **1906**, I, 1436, 1438; Gazz. Chim. Ital., **36**, II, 129.

² Andreasch: Monats. Chem., **8**, 407; **10**, 73, 75; Ber. d. chem. Ges., **31**, 138; Centralb., **1899**, II, 804. Wheeler and Jamieson: J. Am. Chem. Soc., **25**, 366 (1903).

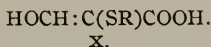
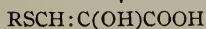
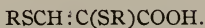
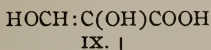
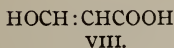
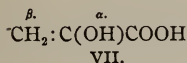
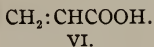
³ *Loc. cit.*

⁴ Ber. d. chem. Ges., **18**, 3243 (1885).

⁵ The writer has signified in a previous paper (THIS JOURNAL, **31**, 290) his intention of condensing diethyl oxalate with diethyl thiodiglycollate.

⁶ Beilstein's Handbuch, Vol. I.

β -mercapto derivatives of acrylic acid (VI), corresponding to α -hydroxy- (VII), β -hydroxy- (VIII), and α,β -dihydroxy-acrylic acids (IX), have been described.



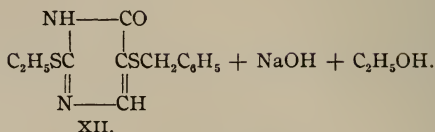
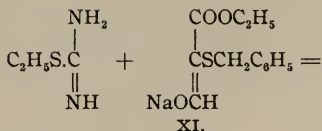
It was, therefore, of especial interest to determine whether ethyl formate would condense with a thioether of ethyl thio-glycollate, $\text{HSCH}_2\text{COOC}_2\text{H}_5$, giving an α -mercapto derivative of β -hydroxyacrylic acid (X).

We prepared, for our experiments, ethyl benzylthioglycollate¹ and now find that ethyl formate condenses smoothly with this ester, in presence of metallic sodium, giving ethyl α -benzylmercapto- β -hydroxyacrylate (XIII). We have also condensed ethyl formate with ethyl benzoylthioglycollate,² $\text{C}_6\text{H}_5\text{COSCH}_2\text{COOC}_2\text{H}_5$, under the same conditions, but have reserved the description of this work for publication in another paper.

The sodium salt of ethyl α -benzylmercapto- β -hydroxyacrylate (XI) condensed smoothly with pseudoethylthio-urea, in an aqueous solution, giving 2-ethylmercapto-5-benzylmercapto-6-oxypyrimidine (XII). This new condensation is represented by the following equation:

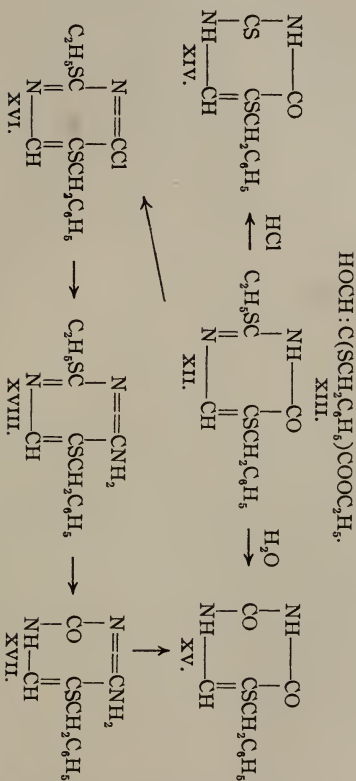
¹ Gabriel: Ber. d. chem. Ges., **12**, 1641.

² Wheeler and Johnson: THIS JOURNAL, **26**, 198.

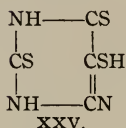
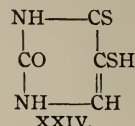
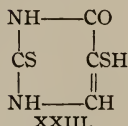
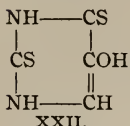
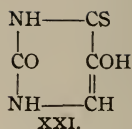
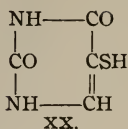
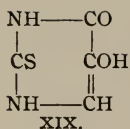


The study of the properties of this pyrimidine was of particular interest because it is the first mercaptopyrimidine to be described which has the mercapto group linked to the 5-position of the pyrimidine ring. Our previous work in this laboratory has been confined to the study of 2- and 4- or 6-mercapto derivatives. The 5-mercapto group in 2-ethylmercapto-5-benzylmercapto-6-oxypyrimidine (XII) is very firmly bound and is not removed by hydrolysis with acids. When the pyrimidine was digested with concentrated hydrochloric acid, it was converted quantitatively into 5-benzylmercaptouracil (XV). On the other hand, when heated above its melting point in a stream of dry hydrochloric acid gas, it was converted smoothly into 2-thio-5-benzylmercapto-6-oxypyrimidine (XIV).

2-Ethylmercapto-5-benzylmercapto-6-oxypyrimidine reacted in a smooth manner with phosphorus oxychloride, giving 2-ethylmercapto-5-benzylmercapto-6-chlorpyrimidine (XVI). When this chlorpyrimidine was heated with ammonia, a quantitative yield of 2-ethylmercapto-5-benzylmercapto-6-aminopyrimidine (XVIII) was obtained. This compound was then converted quantitatively into 5-benzylmercapto-cytosine (XVII) by hydrolysis with hydrochloric acid. These different transformations are represented by the following formulas:



There are 7 possible thiopyrimidines that can be derived from 5-hydroxyuracil by replacement of the oxygen atoms with sulphur, *viz.*, the three monothio derivatives, 2-thio-5-hydroxy-6-oxy-, 2,6-dioxy-5-mercapto-, and 2-oxy-5-hydroxy-6-oxy-pyrimidines (XIX, XX, XXI), the three dithio derivatives, 2,6-dithio-5-hydroxy-, 2-thio-5-mercapto-6-oxy-, and 2-oxy-5-mercapto-6-thiopyrimidines (XXII, XXIII, XXIV), and finally 2,6-dithio-5-mercaptopyrimidine (XXV).



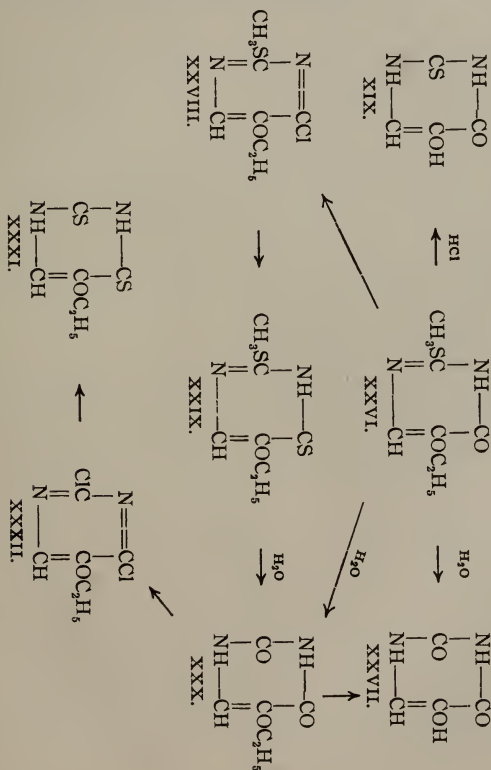
5-Benzylmercaptouracil (XV) and 2-thio-5-benzylmercapto-6-oxypyrimidine (XIV) are the benzyl ethers of 2,6-dioxy-5-mercaptopyrimidine (XX) and 2-thio-5-mercapto-6-oxypyrimidine (XXIII), respectively, and also the first thio ethers of this series of thiopyrimidines to be described.

We have prepared the first member of the series, 2-thio-5-hydroxy-6-oxypyrimidine (XIX), by heating 2-methylmercapto-5-ethoxy-6-oxypyrimidine¹ (XXVI) in a stream of dry hydrochloric acid gas.² An attempt was also made to synthesize 2-oxy-5-hydroxy-6-thiopyrimidine (XXI) from 2-methylmercapto-5-ethoxy-6-oxypyrimidine. The latter compound reacted smoothly with phosphorus oxychloride, giving 2-methylmercapto-5-ethoxy-6-chlorpyrimidine (XXVIII), which was then converted into 2-methylmercapto-5-ethoxy-6-thiopyrimidine (XXIX) by the action of potassium hydrosulphide. All attempts to hydrolyze this pyrimidine to 2-oxy-5-ethoxy-6-thiopyrimidine and 2-oxy-5-hydroxy-6-thiopyrimidine (XXI) were unsuccessful. The 6-sulphur atom is not firmly bound and the pyrimidine underwent hydrolysis with formation of methyl mercaptan and hydrogen sulphide

¹ Johnson and McCollum: *J. Biol. Chem.*, **1**, 447.

² Wheeler and Liddle: *J. Am. Chem. Soc.*, **30**, 1157.

and was converted into 5-ethoxyuracil (XXX). 2,6-Dichlor-5-ethoxypyrimidine (XXXII) was prepared by the action of phosphorus oxychloride on 5-ethoxyuracil (XXX). When this dichlorpyrimidine was warmed with potassium hydrosulphide it was converted quantitatively into the ethyl ether of 2,6-dithio-5-hydroxypyrimidine (XXIII) or 2,6-dithio-5-ethoxypyrimidine (XXXI). These various transformations are represented by the following formulas:



EXPERIMENTAL PART.

Ethyl Benzylthioglycollate, $C_6H_5CH_2SCH_2COOC_2H_5$.—This ester has been described by Gabriel,¹ who prepared it by esterification of benzylthioglycollic acid with ethyl alcohol. We prepared it by the action of sodium benzylmercaptide on ethyl chloracetate. The benzyl mercaptan was dissolved in alcohol containing a molecular proportion of sodium ethylate and the required amount of ethyl chloracetate added. The solution was then heated on the steam bath until it failed to give an alkaline reaction, cooled, and the undissolved sodium chloride filtered off. The excess of alcohol was then removed by heating the mixture to 120° and the crude ester washed with water, dissolved in the ether, and dried over calcium chloride. It was purified by one distillation under diminished pressure and the fraction boiling within 10 degrees at a constant pressure saved for our experiments. The boiling points of four different preparations were 190° – 200° at 30–33 mm., 185° – 200° at 33 mm., 198° – 210° at 50 mm., and 179° – 189° at 23 mm. Thirty-two, 35 and 72 grams of the distilled thioglycollic ester were obtained from 34, 38 and 75 grams, respectively, of benzyl mercaptan.

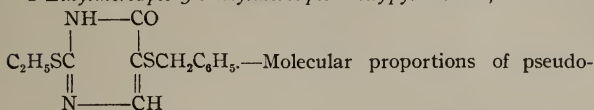
Ethyl α -Benzylmercapto- β -hydroxyacrylate, $HOCH:C(SCH_2C_6H_5)COOC_2H_5$.—The sodium salt of this ester was prepared by adding a mixture of 32 grams of ethyl benzylthioglycollate and 20 grams of ethyl formate, in small portions, to dry ether in which was suspended 4 grams of finely divided sodium. The salt began to deposit at once as a yellow powder, and within 24 hours the sodium had completely disappeared and the condensation was complete. The yield of crude salt was 45 grams. When the salt was dissolved in water and the solution acidified with hydrochloric acid the acrylic ester separated as an oil which solidified when cooled at 0° . After drying in a vacuum over potassium hydroxide and sulphuric acid it melted at 57° – 58° to a clear oil. The ester was very soluble in the common organic solvents and reacted with ferric chloride, giving a bright red color. An attempt to dis-

¹ Ber. d. chem. Ges., **12**, 1641.

til it under diminished pressure was unsuccessful. Sulphur determination (Carius): 0.2527 gram substance gave 0.2654 gram of BaSO₄.

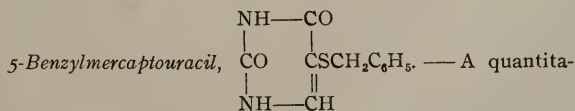
	Calculated for C ₁₂ H ₁₄ O ₃ S.	Found.
S	13.44	14.4

2-Ethylmercapto-5-benzylmercapto-6-oxy pyrimidine,



ethylthiourea hydrobromide (28 grams) and potassium hydroxide (8.5 grams) were dissolved in water and the solutions added successively to a cold, aqueous solution of 45 grams of the sodium salt of ethyl α -benzylmercapto- β -hydroxyacrylate. The mixture was then allowed to stand at ordinary temperature for about 12-14 hours and heated one hour on the steam bath to complete the reaction. The alkaline solution was then cooled, filtered, and acidified with hydrochloric acid. A heavy oil separated and finally crystallized in prisms, melting at 150°-153° to a clear oil. The weight of this crude pyrimidine was 10 grams, and 2 grams more were obtained by extracting the acid solution with ether. The pyrimidine is insoluble in water and difficultly soluble in ether. It crystallizes from 95 per cent. alcohol in four- and six-sided, tabular crystals, which melt at 155°-156° to a clear oil without effervescence. The pyrimidine dissolves in dilute sodium hydroxide solution and is reprecipitated unaltered by addition of acids. Analysis (Kjeldahl):

	Calculated for C ₁₃ H ₁₄ ON ₂ S ₂ .	Found.
N	10.07	10.10



tive yield of this pyrimidine was obtained by digesting 2-

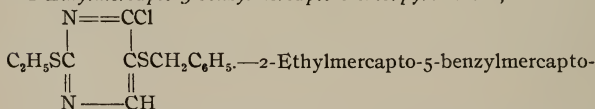
ethylmercapto-5-benzylmercapto-6-oxypyrimidine (3 grams) with strong hydrochloric acid for 4 hours. It is difficultly soluble in hot water and cold alcohol. It crystallizes from boiling 95 per cent. alcohol in rhombic plates or tables, which melt at 290° to a clear oil with decomposition. They gave a strong test for uracil when treated with bromine water and barium hydroxide. Analysis (Kjeldahl):

	Calculated for $C_{11}H_{10}O_2N_2S$.	Found.
N	11.96	11.74

Five-tenths gram of this pyrimidine was heated with 10 cc. of concentrated hydrochloric acid at 130° – 140° for 2 hours. It was recovered unaltered and melting sharply at 290° . The pyrimidine was then heated again at 160° – 170° for 3 hours, when it had been partly decomposed. However, even after this energetic treatment, a small amount of the pyrimidine was recovered unaltered and melting at 290° .

This pyrimidine also dissolves in boiling aniline without change and separates on cooling in plates melting at 290° .

2-Ethylmercapto-5-benzylmercapto-6-chlorpyrimidine,

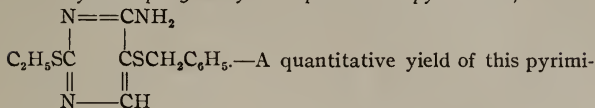


6-oxypyrimidine reacts smoothly with phosphorus oxychloride, giving this chlorpyrimidine. Ten grams of the mercapto-pyrimidine and 40 cc. of phosphorus oxychloride were heated at 120° for 45 minutes, when the evolution of hydrochloric acid had practically ceased. The excess of phosphorus halide was then expelled by heating at 100° under diminished pressure, when a viscous oil was obtained. This was poured into water, warmed gently to decompose any double compound of phosphorus oxychloride, and then extracted with ether. After drying over calcium chloride and evaporating the ether, we obtained the chlorpyrimidine in the form of a dark oil. This solidified on cooling and melted at 40° – 45° . The pyrimidine crystallizes from ligroin in prisms melting at 47° – 48° .

to a clear oil. It is extremely soluble in benzene and alcohol, but insoluble in water. Analysis (Kjeldahl):

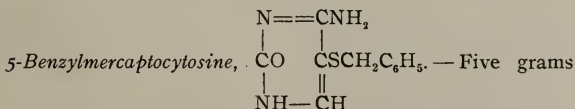
	Calculated for $C_{13}H_{13}N_2ClS_2$.	Found.
N	9.44	9.8

2-Ethylmercapto-5-benzylmercapto-6-aminopyrimidine,



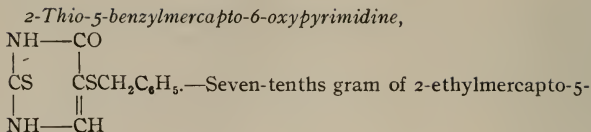
dine was obtained when 5 grams of the above chlorpyrimidine were heated with an excess of an alcoholic solution of ammonia, at 120° – 140° , for 2 hours. After evaporating the excess of alcohol at 100° , the pyrimidine was then separated from ammonium chloride by dissolving it in ether. It is very soluble in ether, ligroin, alcohol and benzene, but insoluble in water. It crystallizes from ligroin in sheaves of needles melting at 68° – 69° to a clear oil. Analysis (Kjeldahl):

	Calculated for $C_{13}H_{15}N_3S_2$.	Found.
N	15.16	14.88



of 2-ethylmercapto-5-benzylmercapto-6-aminopyrimidine were dissolved in 50 cc. of strong hydrochloric acid and the solution boiled for 1.5 hours, when the evolution of ethyl mercaptan had practically ceased. The solution was then evaporated to dryness, the hydrochloride dissolved in water, and the pyrimidine base precipitated by addition of ammonia. It is soluble in hot alcohol and insoluble in water and ether. It crystallizes from 95 per cent. alcohol in plates melting at 240° – 241° . Analysis (Kjeldahl):

	Calculated for $C_{11}H_{11}ON_2S$.	Found.
N	18.01	18.00

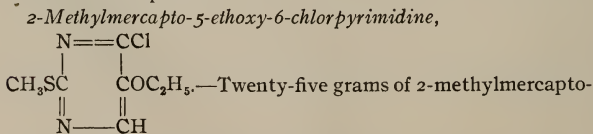


benzylmercapto-6-oxypyrimidine was heated in a current of dry hydrochloric acid gas, at 160° – 170° , until the evolution of ethyl chloride ceased. We obtained a brown substance, which was washed with ether to remove traces of oil and then crystallized from 95 per cent. alcohol. The pyrimidine separated, on cooling, in blocks melting at 195° – 196° to an oil without effervescence. It gave a strong test for sulphur. Analysis (Kjeldahl):

see errata
p. 588

	Calculated for $\text{C}_{11}\text{H}_{10}\text{ON}_2\text{S}_2$	Calculated for $\text{C}_4\text{H}_4\text{ON}_2\text{S}_2$	Found.
N	11.20	17.50	11.57

Attempts to prepare this pyrimidine by condensation of the sodium salt of ethyl α -benzylmercapto- β -hydroxyacrylate with thiourea in aqueous solution, and in alcohol in presence of sodium ethylate, were unsuccessful. For example: one gram of sodium and 3 grams of thiourea were dissolved in alcohol, ten grams of the sodium salt suspended in the solution, and the mixture then digested on the steam bath for 6 hours. There was no indication of any reaction and 8.0 grams of the unaltered sodium salt separated on cooling. The alcohol filtrate was then evaporated to dryness and the residue left behind dissolved in a little cold water and the solution carefully acidified with hydrochloric acid. The solution became turbid, but on standing no pyrimidine separated, showing that no condensation had taken place.



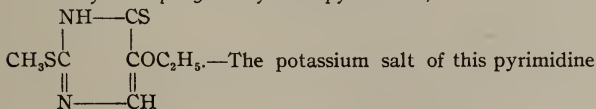
5-ethoxy-6-oxypyrimidine¹ were suspended in 40 cc. of phos-

¹ Johnson and McCollum: *Loc. cit.*

phorus oxychloride. There was an immediate reaction and the pyrimidine dissolved completely. The solution was heated in an oil bath at 120° – 130° for a few hours to complete the reaction, and the excess of phosphorus oxychloride removed by heating at 100° under diminished pressure. An oil was obtained which immediately solidified when poured into cold water. This was a double compound of the pyrimidine and phosphorus oxychloride, and in order to decompose it and destroy the phosphorus halide, it was necessary to triturate it with hot water. The pyrimidine was then dissolved in ether, washed with dilute sodium hydroxide solution and dried over calcium chloride. When the ether was removed we obtained the pyrimidine as a crystalline solid melting at 70° . The yield was 21 grams, or 95 per cent. of the calculated. The pyrimidine is insoluble in water and very soluble in benzene and ether. It crystallizes from 95 per cent. alcohol in slender prisms melting at 75° to an oil. Analysis (Kjeldahl):

	Calculated for $C_7H_9ON_2ClS$.	Found.
N	13.69	13.63

2-Methylmercapto-5-ethoxy-6-thiopyrimidine,

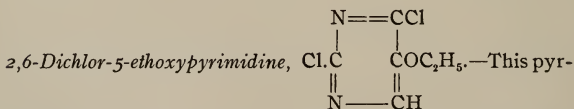


was obtained when 5 grams of 2-methylmercapto-5-ethoxy-6-chlorpyrimidine were dissolved in an alcoholic solution of potassium hydrosulphide and the mixture digested on the steam bath for several hours. The excess of alcohol was then removed by evaporation at 100° and the potassium salt of the pyrimidine and potassium chloride dissolved in water. When this solution was acidified with acetic acid, the 6-thiopyrimidine separated in yellow crystals. It is difficultly soluble in hot water but crystallizes from alcohol in light yellow prisms melting at 190° to a clear oil. The yield was 3.5 grams. Analysis (Kjeldahl):

	Calculated for $C_7H_{10}ON_2S_2$.	Found.
N	13.86	13.78

An attempt to prepare 2-oxy-5-ethoxy-6-thiopyrimidine from this compound, by hydrolysis with hydrochloric acid, was unsuccessful. About 7 grams of the mercaptopyrimidine were digested with a large excess of concentrated hydrochloric acid on the steam bath for several hours. Methyl mercaptan and hydrogen sulphide were evolved and the pyrimidine finally dissolved. The acid solution was then evaporated to dryness and the crystalline substance obtained purified by repeated crystallizations from hot water. It separated in irregular prisms which melted at about 275° to a dark oil. This melting point varies according to the rate of heating. The compound gave no test for sulphur, and a nitrogen determination (Kjeldahl) agreed with the calculated value for 5-ethoxyuracil.¹ The small amount of material which accompanied this 5-ethoxypyrimidine and rendered the purification difficult contained sulphur, but we did not succeed in isolating a sufficient quantity of the substance in pure state for analysis. Its melting point, 190° – 230° , indicated a mixture.

	Calculated for $C_6H_8O_2N_2$.	Found.
N	17.94	17.80



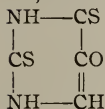
imidine was prepared by the action of phosphorus oxychloride on 5-ethoxyuracil.¹ Twelve grams of the ethoxyuracil and 70 cc. of phosphorus oxychloride were digested at 120° – 130° for nearly 3 hours before the evolution of hydrochloric acid ceased. The dark liquid was then filtered from a small amount of insoluble, amorphous substance and the excess of phosphorus halide removed, in the usual manner, by heating at 100° under diminished pressure. We obtained a thick syrup

¹ Johnson and McCollum: *Loc. cit.*

which solidified when poured into cold water. In order to destroy all phosphorus halide, this substance was then melted under water by heating the liquid to 60° – 70° , and after thorough mixing the pyrimidine was dissolved in ether. The ether solution was then dried over calcium chloride and the excess of ether removed by spontaneous evaporation, when the pyrimidine separated in well-developed prisms. It is soluble in cold alcohol, benzene and petroleum ether and crystallizes from the latter in clusters of radiating prisms and needles which melt at 41° – 42° to a clear oil. It crystallizes from water in prisms melting at the same temperature. The yield was about 75 per cent. of the calculated. Analysis (Kjeldahl):

	Calculated for $C_6H_8ON_2Cl_2$.	Found.
N	14.50	14.35

2,6-Dithio-5-ethoxypyrimidine (5-Ethoxydithiouracil),



—This compound was prepared by the action of potassium hydrosulphide on 2,6-dichlor-5-ethoxypyrimidine in alcoholic solution. It is soluble in hot alcohol and crystallizes, on cooling, in needles which slowly decompose when heated above 255° , and effervesce violently at about 267° – 268° . The pyrimidine is insoluble in water. Analysis (Kjeldahl):

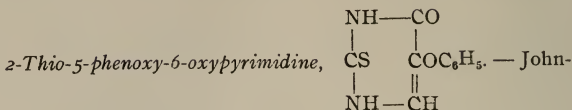
	Calculated for $C_6H_8ON_2S_2$.	Found.
N	14.7	14.9

Sodium Salt of Ethyl α -Phenoxy- β -hydroxyacrylate,

$\text{NaOCH: C(OC}_6\text{H}_5\text{)COOC}_2\text{H}_5$.—Johnson and Heyl¹ prepared this salt by condensation of ethyl formate with ethyl phenoxyacetate in presence of sodium ethylate. The use of sodium ethylate is unnecessary and a practically quantitative yield of the salt can be obtained if the esters are condensed in ether in the presence of metallic sodium. Thirty-one grams of

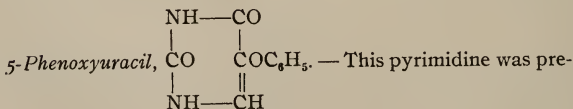
¹ THIS JOURNAL, 37, 636.

crude, dry salt were obtained from 25 grams of ethyl phenoxy-acetate.



son and Heyl¹ have shown that the above sodium salt condenses with pseudoethylthiourea, in aqueous solution, giving 2-ethylmercapto-5-phenoxy-6-oxypyrimidine. Fifteen grams of thiourea and 4.5 grams of sodium were dissolved in alcohol and 31 grams of the sodium salt dissolved in the solution by warming on the steam bath. After digesting for 10 hours, the excess of alcohol was removed by evaporation at 100° and the residue remaining dissolved in cold water, filtered, and the solution acidified with acetic acid. Sixteen grams of the crude pyrimidine separated as a colorless, granular powder. It is insoluble in hot water, moderately soluble in alcohol, insoluble in benzene and soluble in acetic acid. It crystallizes from acetic acid in clusters of prisms showing a twinning habit, and melts at 253°–254° to a brown oil. Nitrogen (Kjeldahl) and sulphur (Carius) determinations gave the following results:

	Calculated for C ₁₀ H ₈ O ₂ N ₂ S.	I.	Found.	II.
N	12.73	12.82		...
S	14.56	14.30		14.72



pared by heating 2-thio-5-phenoxy-6-oxypyrimidine (2 grams) with concentrated hydrochloric acid (35 cc.) at 140°–160°, and also by digestion with hydrobromic acid for several hours. It is practically insoluble in cold water and alcohol and difficultly soluble in hot water. It crystallizes from boiling acetic acid

¹ *Loc. cit.*

in distorted needles melting at 290° with effervescence. Analysis (Kjeldahl):

	Calculated for $C_{10}H_8O_3N_2$.	Found.
N	13.72	13.62

NEW HAVEN, CONN.,
June, 1909.

[Contributions from the Chemical Laboratory of Harvard College.]

A MODIFICATION OF SCHEIBLER'S EXTRACTOR FOR USE WITH LARGE QUANTITIES OF A SOLID.

BY C. LORING JACKSON AND LATHAM CLARKE.

In the course of the investigation of curcumin which has been carried on for some time in this laboratory, it was necessary to extract large quantities of turmeric with ligroin and ether; for this purpose, a modification of Scheibler's extractor¹ was contrived which we think is worth describing, although it embodies no new principle, as by doing this we may save others from struggling with the difficulties which it has cost us some trouble to overcome.

The first extractor constructed was of moderate size and made of tinned iron. It lasted in good condition for twelve years, but when ten years later we took up the research again it was found to have been destroyed by rust, and a new one was made of copper for greater durability. Later a much larger extractor capable of holding 18 kilograms of turmeric was made. We will describe this first, afterward giving a brief account of the smaller form.

The vessel for holding the substance to be extracted was a copper cylinder A, 46 cm. high and 40 cm. in diameter, the vertical sides of which were surrounded with a jacket B, 2 cm. thick, furnished with two tubulures, C and D, 3 cm. long and 1.2 cm. in outer diameter, one at the top and one at the bottom, by means of which the jacket could be filled with steam. The only means of access to the inner cylindrical space were three tubulures, F, O, P. One of these, F, was 2

¹ Ber. d. chem. Ges., 13, 338 (1880).

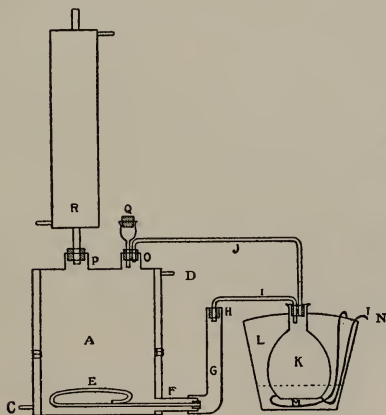
cm. from the bottom of the cylinder, and so placed that it did not interfere with the tubulures C, D, of the jacket. It was 3 cm. in outside diameter and 10 cm. long, made of heavy copper and the outer end provided with a screw thread, by which was attached the copper elbow G, 33 cm. high. This screw joint was found in our case to be tight without luting. The two other tubulures were in the fixed cover of the cylinder. One, O, was placed above the lower tubulure F, the other, P, on the opposite side of the cover, each being 6 cm. from the edge. They were 5 cm. in diameter and 5 cm. high.

To set up the apparatus, a spiral door spring was pulled out, so as to make a long thin spiral tube, leaving, however, one end of the original diameter. The long part was then covered with two thicknesses of cheese cloth securely sewed on, and the thick end fixed in the hole of a cork, which filled the lower tubulure F. The long flexible tube E, thus prepared, was pushed into the lower tubulure, so that it coiled in a spiral on the bottom of the containing vessel, and the cork was fixed in the mouth of F, after which the elbow G was screwed on. The cylindrical vessel was then filled, through the tubulures O and P, with the powdered substance to be extracted, the surface smoothed off so that it lay 4 cm. below the cover, and the condenser fitted to P. It was found necessary to have large corks especially cut for use in these wide tubulures. The condenser R was a copper tube 64 cm. high and 16 cm. in outer diameter, containing a worm made of copper tube 2 cm. in outside, 1.7 cm. in inside diameter, and was found entirely effective.

The tubulure O was closed with a cork having three holes in it; one carried a thistle tube Q with a diameter of about 4 cm. at the top, which was closed with a cork while the apparatus was running; the other two holes carried the delivery tubes J from the two flasks in which the extracting liquid was boiled.¹ These delivery tubes can be wound with cloth, if it is found necessary, but it was not in our case, as the apparatus was set up in a cupboard which was kept

¹ In the diagram only one of the flasks is represented to avoid complication. The second flask stood at the side of the first, and was mounted in the same way.

warm by the steam coils used in boiling the extracting liquid. The two syphon tubes I, which conveyed the extract from the containing vessel to the flasks, were inserted in the top of the metallic elbow G with a doubly bored cork H, and the joint made tight with a thin layer of linseed meal strengthened by about 2 cm. of plaster of Paris. The height of these syphons must be carefully adjusted so that they cease running when a sufficient amount of liquid has passed over into the flasks. This height must be found by experiment. In our apparatus the upper angle of the syphon was 8 cm. below the top of the cylinder, and the arm within the flask was 7 cm. long from the bend. One syphon was about 1 mm. lower than the other.



Each of the 3-liter flat-bottomed flasks, K, stood in a pail, L, containing enough glycerol and water to rise to a height of about 4 cm. on the flask, and this bath was heated by a single coil of heavy lead pipe, M (2 cm. in external diameter), through which steam was passed. The advantage of this arrangement was that in case the flask broke, the liquid would

be caught in the pail, thus making it possible to recover the greater part of it and diminishing the danger of fire.

After the apparatus had been filled with the substance to be extracted and set up, the extracting liquid was poured in through the thistle tube Q, until a convenient amount of it had flowed through the syphons into the flasks. The thistle tube was then corked, and the steam turned on in the pails. When a sufficient amount of the liquid had distilled over to rise above the bend of the syphon, which was about 1 mm. lower than the other, this began to draw the liquid back into its flask, while the pressure of the vapor in the other flask stopped its syphon from flowing until the distillation from it had come to an end, when this second syphon came into action instead of the first. In this way the flasks acted alternately, one losing its liquid by distillation, while the other was receiving a fresh supply by its syphon. The first adjustment of our apparatus took about an hour. After this it took five minutes each morning to start it, and then it ran without attention, until the steam was turned off in the evening. The extract was removed from the flasks as it accumulated, and fresh liquid added through the thistle tube as necessary.

When the extraction was finished, the end of the condenser R was stoppered, one flask removed, and its cork stoppered by a wide tube like a test tube, the delivery tube of the other flask stoppered, and a vessel large enough to hold the liquid placed under its syphon. The thistle tube, Q, was then fitted with a cork carrying a bent tube, through which air was pumped into the apparatus from a bellows until no more liquid flowed out through the syphon. The cork of the second flask was then stoppered with a wide test tube like that of the first one, the bent tube in the thistle connected with a condenser, and the jacket, B, kept full of steam until all the liquid had distilled off, after which the dry powder was emptied out of the cylinder through the tubulures O and P.

The smaller extractor was similar in construction but simpler and had the following dimensions: The cylinder, 30 cm. high and 28 cm. in outer diameter, the upper tubulures O and P, 4 cm. high and the same in diameter, the lower side

tubulure F, 2.25 cm. in diameter and 4 cm. long. Only one flask was used, the glass syphon from which was fitted to the lower tubulure F with a cork tightened with linseed meal. The syphon projected several cm. into the cylinder, and its end was covered with cheese cloth. In putting the apparatus together, advantage was taken of the elasticity of the glass tubes. This smaller extractor is large enough for most purposes.

REVIEWS.

DIE NEUEREN FORTSCHRITTE AUF DEM GEBIETE DER RADIOAKTIVITÄT (von Anfang 1906 bis Mitte 1908). Von DR. HEINRICH GREINACHER, Privatdozent an der Universität Zürich. Braunschweig: Druck und Verlag von Friedrich Vieweg und Sohn. 1908. pp. 47. Price, M. 1.20.

This brochure is a welcome addition to our literature on radioactivity. The subject has been developed so rapidly that it is almost impossible for the larger standard works to keep pace with the developments in this field. To do so would require a new edition of such works at least once a year. This pamphlet is a summary of the more important facts established recently, and especially during the past two years. It is recommended to all who are interested in radioactive phenomena, and what man of science is not interested in them?

H. C. J.

DIE ENGLISCHEN ELEKTROCHEMISCHEN PATENTE. Auszüge aus den Patentschriften, zusammengestellt und mit ausführlichem Sack- und Namen-register versehen. Von DR. P. FERCHLAND, Patentanwalt in Berlin. Zweiter Band: Elektrothermische Verfahren und Apparate; Entladungen durch Gase. Mit 417 Figuren im Text. Halle a/S: Druck und Verlag von Wilhelm Knapp. 1908. pp. 190. Price, M. 9.60.

The contents of this book is indicated by the title. It is a collection of patents with a very large number of illustrations of the apparatus used. The book covers a wide scope, dealing with the methods employed in preparing the metals, carbides, cyanogen, etc. Such a compilation will doubtless be of convenience and value to the technical electrochemist. H. C. J.

GRUNDRISS DER ALLGEMEINEN CHEMIE. Von WILHELM OSTWALD. Vierte, völlig umgearbeitete Auflage. Leipzig: Verlag von Wilhelm Engelmann. 1909. pp. 661. Price, M. 20.

The "Grundriss" by Ostwald has, as is well known, played a prominent part in the development of the new physical chemistry. Its comparatively small size in the earlier editions, and its relatively elementary character made it ac-

cessible to a large number of readers. This book has doubtless determined the career of many a young man, by giving him a glance at the generalizations which have contributed so much towards the development of a scientific chemistry.

This edition is larger than the preceding—new matter being added to the older chapters, and it contains new chapters on the gas ions, radioactivity, and colloids.

For those who are familiar with Ostwald's earlier views, it is interesting to find the following statement:

"Ich habe mich überzeugt, dass wir seit kurzer Zeit in den Besitze der experimentellen Nachweise für die diskrete oder körnige Natur der Stoffe gelangt sind, welche die Atomhypothese seit Jahrhunderten, ja Jahrtausenden, vergeblich gesucht hatte. Die Isolierung und Zählung der Gasionen einerseits, welche die langen und ausgezeichneten Arbeiten von J. J. Thomson mit vollem Erfolge gekrönt haben, und die Übereinstimmung der Brownschen Bewegungen mit den Forderungen der kinetischen Hypothese andererseits, welche durch eine Reihe von Forschern, zuletzt am vollständigsten durch J. Perrin, erwiesen worden ist, berechtigen jetzt auch den vorsichtigen Wissenschaftler, von einem experimentellen Beweise der atomistischen Beschaffenheit der raumerfüllenden Stoffe zu sprechen. Damit ist die bisherige atomistische Hypothese zum Range einer wissenschaftlich wohlbegründeten Theorie aufgestiegen, und darf ihre Stelle auch in einem zur Einführung in das Wissensgebiet der allgemeinen Chemie bestimmten Lehrbuche beanspruchen."

This fourth edition of the "Grundriss" is a valuable addition to physical chemical literature, and will doubtless contribute materially towards the expansion of that branch of science with whose foundation it has had so much to do.

H. C. J.

DIE EDLEN UND DIE RADIOAKTIVEN GASE. VON SIR WILLIAM RAMSAY, K.C.B., Nobel Laur., Professor an der Universität London. Vortrag, gehalten im österreichischen Ingenieur- u. Architekten-Verein zu Wien. Leipzig: Akademische Verlagsgesellschaft M. b. H. 1908. pp. 39. Price, M. 1.40.

This is an extremely interesting lecture by Ramsay on the discovery of argon, helium, neon, xenon and krypton in atmospheric air. Sketches of a number of the pieces of apparatus employed are given and spectrograms are included showing the most characteristic lines of the several elements.

The lecture concludes with an account of the work of Ramsay and Cameron on the decomposition of the radium emanation under various conditions.

H. C. J.

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[From the Division of Chemistry, Hygienic Laboratory, U. S. Public Health and Marine Hospital Service, Washington, D. C.]

ON THE DECOMPOSITION OF THE LEUCOSULPHONIC ACIDS OF ROSANILINE HYDROCHLORIDE AND CRYSTAL-VIOLET IN AQUEOUS SOLUTION.

By J. H. KASTLE.

The fact that the coloring matters of certain flowers can be bleached by sulphur dioxide has been known for a long time. Through the researches of Schoenbein¹ on this subject it was established that the color of indigo and the coloring matter of certain flowers, such as that of the purple dahlia, which had been bleached by means of sulphur dioxide can be restored by means of acids and alkalies, by methyl and ethyl alcohols, and by oil of bitter almonds; by oxidizing agents such as ozone, ozonized turpentine, chlorine, bromine, iodine, and hypochlorites; by hydrogen sulphide; and, most remarkable of all, by heating to 100° C., and even by cooling to low temperatures by freezing mixtures. Thus he was able to alternately color and bleach a rose, which had been bleached in sulphur dioxide, no less than thirty times in one minute by

¹ Schoenbein: Verh. Naturf. Ges., Basel, **1**, 5-8 11-13, 13-16 (1854-1857); **2**, 15-20 (1858-1860).

alternately heating and cooling it in an atmosphere of hydrogen.

In 1905 Kastle¹ confirmed a number of these earlier observations, and pointed out that the affinities of acids can be determined colorimetrically by means of certain vegetable coloring matters which had been bleached by means of sulphur dioxide. Later Kastle and Amoss² employed a solution of the coloring matter of the red cabbage (*Brassica oleracea*) which had been bleached by means of sulphur dioxide as a reagent for the detection of free hydrochloric acid in gastric contents and its estimation colorimetrically.

The principal difficulty which has been encountered in the use of such reagents is that they are unstable and hence have to be prepared fresh from time to time, and the materials employed can be obtained only at certain seasons of the year. Attempts have therefore been made by the writer from time to time during the past two or three years, though without success, to find an artificial coloring matter, the sulphurous acid leuco-compound of which would conduct itself towards acids as do the corresponding leuco-compounds of certain of the vegetable coloring matters. Such being the case I have recently had one of the assistants in the Hygienic Laboratory, Mr. F. A. McDermott, try the action of sulphurous acid on a large number of artificial dyes. A few of the dyes thus far tested have been found to be bleached by sulphur dioxide. Thus far, however, we have failed to find an artificial dye whose sulphurous acid leuco-derivative is decomposed by acids with the regeneration of the original color.

It has been found, however, that certain dyes of the parosaniline hydrochloride type yield colorless aqueous solutions when treated with sulphur dioxide, and that the color of such solutions is restored by boiling off the sulphur dioxide. Similar results were obtained by Schoenbein³ in his work on the action of sulphur dioxide on cyanine (quinoline-blue). He showed that moist cyanine paper is rapidly bleached by sulphur dioxide, and that on exposure to the air such bleached cyanine

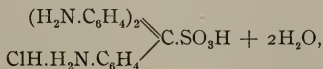
¹ THIS JOURNAL, **33**, 46-59 (1905).

² P. Am. Soc. Biol. Chem., **1**, 20-21 (1907).

³ Verh. Naturf. Ges., Basel, **4**, 215-218 (1864-1867).

paper rapidly turns blue, and that on the same strip of paper this alternate bleaching and bluing may be observed in rapid succession by exposing the paper first to sulphur dioxide and then to air. According to this author the cause of the bluing of the bleached cyanine paper lies in the instability of the colorless compound, which is so great that sulphur dioxide is given off from it even at ordinary temperatures, in much the same way that ammonia and carbon dioxide are given off from ammonium carbonate.

It therefore occurred to me that aqueous solutions of such leuco-compounds would, in all probability, exhibit the phenomenon of dissociation by heat. As a matter of fact my experiments with the leucosulphonic acids of rosaniline hydrochloride and crystal-violet indicate that such is really the case. Our knowledge of these compounds dates from 1867, when Schiff¹ prepared the so-called fuchsine-sulphurous acid and recommended its use as a reagent for aldehydes. The leuco-compound resulting from the action of sulphur dioxide on fuchsine (pararosaniline hydrochloride) was first isolated in pure condition by Hantzsch and Osswald.² According to these authors this compound, to which they have given the name "Pararosaniline-hydrochloride-leucosulphonic acid," has the constitution



and when first prepared is colorless and crystalline, but on drying it becomes faintly red. They called attention to its instability and to the ease with which it is resolved into its components; thus they observed that sulphur dioxide is partially expelled from the compound by a current of carbon dioxide even in the cold, whereby the coloring matter (pararosaniline hydrochloride) is regenerated. They also accounted for the difficulty and failure on the part of other chemists to obtain the acid as due partly to the instability of the compound and partly to the sparing solubility of fuchsine in water.

¹ Bull. Soc. Chim., [1] **7**, 518 (1867); Compt. Rend., **64**, 182 (1867).

² Ber. d. chem. Ges., **33**, 310-311 (1900).

A few years later, Dürschnabel and Weil¹ also investigated the action of sulphurous acid on certain triphenylmethane coloring matters. In their work, however, they employed the free bases of these dyes, not the salts, and while the derivatives they obtained are of great interest, they differ essentially in composition, constitution and properties from the sulphurous acid derivatives of the salts of the dyes of the pararosaniline type described by Hantzsch and Osswald,² and hence warrant no further consideration in this connection.

So far as I have been able to discover, no observations have been recorded by the above-named chemists or by others on the decomposition of the leucosulphonic acids of the dyes of the pararosaniline hydrochloride type in aqueous solution. That aqueous solutions of such compounds are readily decomposed by heat is indicated by the following observations:

Dilute solutions of rosaniline hydrochloride and crystal-violet, containing about 0.05 gram of the dye in 50 cc. of water, were decolorized by means of sulphur dioxide. Such solutions may be preserved unchanged in glass-stoppered bottles, under ordinary conditions prevailing in the laboratory, for several days, and possibly for longer intervals. The mouths and necks of the bottles, however, gradually show the colors of the dyes in their original tints, *viz.*, red and violet. Similarly if a drop of these colorless solutions be placed upon filter paper, a red or blue ring gradually appears as the solutions evaporates, and pieces of linen or cotton cloth may be dyed red or blue by immersion in these solutions and drying in the air. So, also, if these colorless solutions are boiled for a long time so as to remove the sulphur dioxide, deep bluish-violet and red solutions are obtained whose colors are permanent. Obviously these changes of color result from the decomposition of the unstable leucosulphonic acids, either spontaneously as the result of the action of heat, or through the action of the oxygen or carbon dioxide of the air, or as the result of the combined action of heat and water. On the other hand, if the colorless solutions of the leucosulphonic acids of these dyes be boiled

¹ Ber. d. chem. Ges., **38**, 3492-3496 (1905).

² *Loc. cit.*

for only a short time, in order not to remove all of the sulphur dioxide, the solutions become colored red and blue, respectively, and these colors persist as long as the solutions remain hot. If now they be cooled by plunging the tubes into cold water, the colors fade rapidly and the solutions again become colorless. These changes, as brought about by the alternate heating and cooling, have been repeated several times on the same solution. In such cases, therefore, it would seem either that the oxygen or carbon dioxide of the air did not act through a sufficiently long interval to completely decompose these leuco-compounds, or that these color changes were the result of the dissociation of the leucosulphonic acids by heat, or of their hydrolytic dissociation.

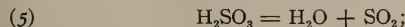
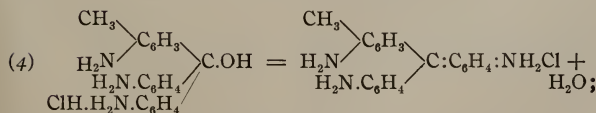
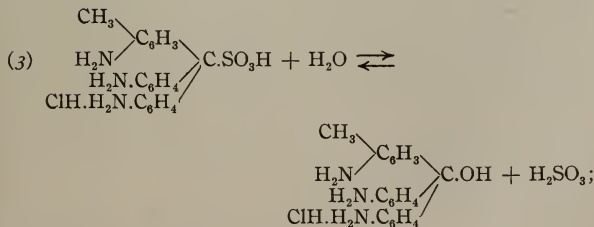
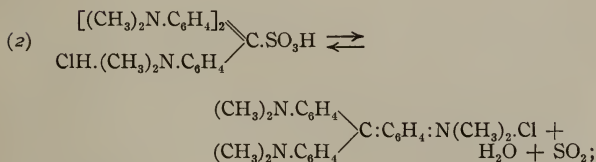
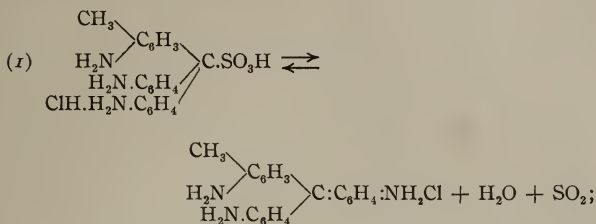
In order to throw further light on these phenomena, a number of sealed tubes were prepared containing about three cubic centimeters of the colorless solutions of these leuco-compounds, the space above the liquid in the tube, about 6 cc., being filled with air. These tubes were then placed in boiling water. In from one to two minutes, the solutions had become red and bluish-violet, respectively. When the hot tubes were immersed in cold water, the colored solutions bleached rapidly, 30 seconds to one minute being required for complete decolorization. With the tubes first prepared for this purpose, these phenomena, *viz.*, coloration by heating to 100° C., and decolorization by cooling to ordinary temperatures, have been repeated fifteen times, and after standing under ordinary laboratory conditions for two days, the tubes were found to be as sensitive to the effect of heat and cold as they were when first prepared.

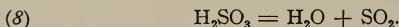
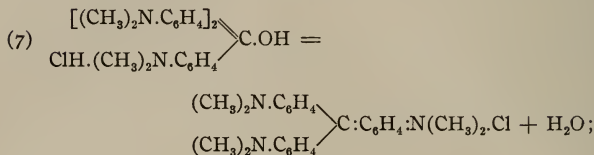
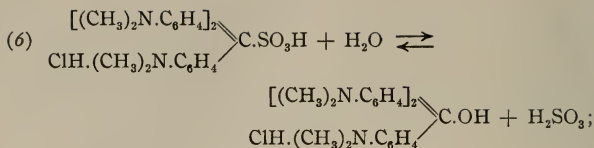
In order to exclude the effect of carbon dioxide or oxygen of the air on the changes under consideration, three tubes or glass bulbs were prepared, containing small amounts of the leucosulphonic acid of crystal-violet, and labeled No. 1, No. 2, and No. 3. Tube No. 1 was then connected with the vacuum pump for fifteen minutes; under the influence of the vacuum, considerable amounts of sulphur dioxide boiled off, the effect of which, together with that of the vacuum, was certainly to remove all except the merest traces of oxygen

and carbon dioxide. The tube, while still connected with the pump, was sealed in the flame of the blowpipe. Through Tube No. 2, a current of hydrogen was passed in order to drive out all of the air, and the tube sealed in the flame while the current of hydrogen was still passing through it. Tube No. 3, which was in the form of a bulb with a long narrow neck, 1 to 2 mm. in diameter, was filled with the solution of the leucosulphonic acid of crystal-violet to a point very near the orifice, and heated in a bath of boiling water for five minutes. Under these conditions, the sulphur dioxide and the overflow from the liquid, due to expansion by heat, displaced the air. The tube was then sealed in the flame while still in the bath of boiling water. On heating in a bath of boiling water, the solutions contained in these three tubes became deep bluish-violet in color in from 30 seconds to one minute, this change from colorless to bluish-violet occurring first on the upper surface and in the upper layers of the liquid. On immersion in cold water, Tube No. 3 became colorless in from 30 seconds to one minute; Tubes Nos. 1 and 2 required a longer time to decolorize completely, usually 20 to 30 minutes, but at the end of this time, neither showed the slightest trace of color. On the day on which these tubes were prepared, these phenomena were repeated a number of times, and on the following day they were repeated again. Three days later these tubes showed precisely the same changes of color on heating and cooling that they showed on the day on which they were prepared, and after an interval of forty days they still showed the same changes of color on heating and cooling.

It is evident, therefore, that the decomposition of the leucosulphonic acids of the dyes of the pararosaniline type, in aqueous solution, is a reversible process and that atmospheric air is not responsible for the changes of color observed when such solutions are heated and cooled. Whether the change in question is one of simple dissociation by heat, as indicated in equations (1) and (2), or whether it is a hydrolytic dissociation, as indicated by equations (3), (4), (5), (6), (7) and (8), can only be determined by quantitative

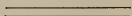
measurements, which will require more time than I can devote to the subject at present. My own opinion is that the latter view is more probable and that the change in question is one of hydrolytic dissociation. This I hope to demonstrate by quantitative measurements at the first opportunity.





In support of the view that the changes observed on heating aqueous solutions of these leucosulphonic acids are due to dissociation, simple or hydrolytic, may be mentioned the fact that the production of the dye by the action of heat takes place first on the upper surface and in the upper layers of the liquid, and that the larger the amount of sulphur dioxide present in the solution of the leucosulphonic acid of the dye, the smaller the quantity of coloring matter produced on heating the solution and the more rapid the bleaching of the colored liquid on cooling, indicating, as might be expected if these changes are due simply to dissociation, that an excess of one of the products of the dissociation depresses the decomposition to a certain extent, and correspondingly hastens the formation of the leucosulphonic acid from the products of the decomposition.

The strikingly beautiful character of these color changes and the ease with which aqueous solutions of the leucosulphonic acids of these dyes can be prepared and handled are such as to render these compounds especially useful on the lecture table for the illustration of reversible phenomena.



[Contribution from Kent Chemical Laboratory of the University of Chicago.]

ON THE ACTION OF FEHLING'S SOLUTION ON MALT SUGAR.

By W. LEE LEWIS.

The following pages contain a report of a preliminary and incomplete investigation carried out by myself, at the suggestion and under the direction of Dr. Nef, of the products formed in the oxidation of malt sugar by alkaline solutions containing cupric hydroxide (Fehling's solution). The work shows that the ratio of the various acids—carbonic, formic, glycollic, hexonic, and probably glycerinic and trioxybutyric—formed in this oxidation differs very decidedly from that observed by Nef¹ in the case of dextrose, laevulose, and mannose, respectively. Furthermore, a new hexonic acid, probably α -oxymethyl-*d*-ribonic, is formed in the case of maltose in place of α -oxymethyl-*d*-arabonic acid.² Whereas the simple hexoses named give *d*-gluconic and small amounts of *d*-mannonic acid, malt sugar gives large quantities of glucosido-*d*-mannonic acid only, for reasons already emphasized by Nef.³ It is certain also that oxidation of maltose by Fehling's solution is not accompanied by any very appreciable hydrolysis into two molecules of *d*-glucose, the main oxidation products formed in this case being glucosido monobasic acids whose separation as such cannot as yet be accomplished. A slight splitting of maltose into two molecules of dextrose before oxidation may possibly occur, since the subsequent hydrolysis of the glucosido acids formed always gave less dextrose than would result if only one-half of the malt sugar molecule, *i. e.*, the aldehyde portion, $C_6H_{12}O_6$, $CH_2OH-CHOH-CHOH-CHOH-CHOH-CHO$, had been oxidized. Thus the hydrolysis of the glucosido acids obtained from 24 grams of maltose which are not affected by boiling Fehling's solution gave in four independent experiments, on heating for 10 hours at 100° with five per cent. sulphuric

¹ Nef: Ann. Chem. (Liebig), **357**, 259.

² Nef: Ann. Chem. (Liebig), **357**, 298; Thesis of H. A. Spoehr soon to be published in THIS JOURNAL.

³ Nef: Ann. Chem. (Liebig), **357**, 232.

acid, a mean of 10.145 grams of *d*-glucose, and three similar experiments with 144 grams of maltose gave 47.67 grams, 55.04 grams, and 48.40 grams dextrose, respectively. Assuming that the malt sugar used contained the usual quantity, one molecule, of crystal water, the amount of *d*-glucose theoretically possible on subsequent hydrolysis of the glucosido acids would be exactly one-half of the sugar originally used. When we bear in mind, however, that *d*-glucose itself is not entirely unchanged on heating with 5 per cent. sulphuric acid at 100°, it is clear from the above statement of facts that the malt sugar molecule oxidizes mainly as such with Fehling's solution, giving glucosido acids. These latter are of especial interest because of their possible bearing on the constitution of malt sugar itself. Furthermore, the well-known fact that one molecule of dextrose, $C_6H_{12}O_6$, takes up 2.48 atoms of oxygen, whereas one molecule of maltose, $C_{12}H_{22}O_{11}$, requires only 2.86 atoms when treated with Fehling's solution, now demands no further explanation.

Perhaps the most striking contrast to be noticed between malt sugar, on the one hand, and the simple hexoses—dextrose, laevulose, and mannose—on the other, is the marked difference in the relative amounts of formic and carbonic acids formed in the treatment with the reagent named. One hundred grams of malt sugar gave 3.60 grams of formic acid and 7.37 grams of carbon dioxide, whereas 100 grams of a simple hexose gave from 2.0 to 4.0 grams of carbon dioxide and from 12.0 to 14.0 grams of formic acid.¹

The following further difference is also noteworthy: Mannose, dextrose and laevulose gave, besides glycollic and hexonic acids, large amounts of glycerinic and trioxybutyric acids. In the case of maltose, I was unable to establish (by hydrolysis) with certainty the presence of any monobasic acids containing three or four carbon atoms.

It is therefore already certain that the aldehyde portion of the maltose molecule must be oxidized, under the conditions named, in a manner considerably different from that of the oxidation of simple aldohexoses. It would, however,

¹ Nef: Ann. Chem. (Liebig), **357**, 259.

be premature to develop any theory on this point until certainty has been gained as to the complete nature and relative amounts of the various oxidation products formed from malt sugar.¹

EXPERIMENTAL PART.

Six 24-gram lots of Kahlbaum's maltose, melting at 106°-112°, were worked up in the following manner: Twenty-four grams of maltose were dissolved in 70 cc. of water, and solutions containing 95.6 (2.86 mols. O) grams of hydrated copper sulphate in 300 cc. and 181.0 grams of crystallized barium hydroxide in 750 cc. of water were also prepared. The quantity of copper sulphate used was that just reduced by the 24 grams of maltose under the conditions, and is practically identical with the ratio in use in titrating maltose with Fehling's solution in the usual manner. The barium hydroxide taken was one and a half molecules, calculated against the copper sulphate. Preliminary attempts with three molecules of sodium hydroxide in place of the barium hydroxide failed because of the difficulty of recovering the acids quantitatively from the resulting salt mixture.

All three solutions were heated to boiling and the unfiltered barium hydroxide solution was added slowly with active shaking to the solution of copper sulphate. The hot solution of sugar was similarly added to the mixture and the whole heated in a boiling water bath for one hour with occasional shaking. Reduction, which always started immediately and proceeded rapidly, was complete in this time, as evidenced in the almost entire disappearance of the copper-blue color from the solution. The calculated amount of sulphuric acid was now added, the mixture filtered, and the well-washed, bulky precipitate twice taken up and boiled in 500 cc. of water containing two grams of sulphuric acid. The collected filtrates, which showed no reduction of Fehling's solution, were freed from copper by saturation with hydrogen sulphide, then a very slight excess of barium added, and the water

¹ Work on the further determination of the nature of the products formed from maltose by Fehling's solution, as well as by the oxidation of alkaline solutions of malt and milk sugar by air and by hydrogen peroxide, is at present being continued by Dr. Nef and his students in this laboratory.

and volatile formic acid distilled off at 12 to 25 mm. pressure, the solution being finally heated for one-half hour on the boiling water bath. The residue of acids appeared as a golden brown, slightly mobile syrup. Six such operations with a total of 144 grams of maltose, corresponding to 136.8 grams of the anhydrous sugar, gave 132.8 grams of nonvolatile acids.

Determination of Carbon Dioxide.—Carbon dioxide was determined in independent experiments as follows: Solutions of maltose and copper sulphate were prepared as at first and also a solution of sodium hydroxide containing 46.1 grams (three molecules) in 400 cc. of water. The solutions were well mixed cold—the alkali with the copper sulphate and the sugar with this mixture—and finally boiled in a water bath for one and one-half hours. After filtering off the cuprous oxide the carbon dioxide was set free with hydrochloric acid, calculated for one-third of the alkali used, and driven out of the solution by heating in a flask connected successively with a reversed condenser and with three tall cylinders filled with a saturated aqueous solution of barium hydroxide. The acid was added slowly by means of a separatory funnel, and to insure complete expulsion of the soluble gases, the liquid was finally heated in a bath at 110° – 120° for two hours. During the experiment, air freed from carbon dioxide was drawn slowly through the solution. The precipitated barium carbonate was then filtered off, well washed, and dried at 100° . Control experiments were run for the amount of carbon dioxide in the reagents used, and proper deductions made. Twenty-four grams of sugar gave 7.93 grams of barium carbonate, corresponding to 1.77 grams of carbon dioxide.

Determination of Volatile Acids.—The distillates from each 24-gram lot of maltose, amounting to 3.5-4 liters, were separately made up to definite volume and an aliquot portion titrated with N/10 sodium hydroxide and phenolphthalein as an indicator. These results were checked by the method of H. C. Jones¹ for determining formic acid quantitatively which depends upon its conversion in alkaline solution into

¹ THIS JOURNAL, 17, 537. Cf. Lieben: Monats. Chem., 14, 146; and Péan de St. Gilles: Ann. Chim. Phys., [3] 55, 388.

carbonate with N/10 potassium permanganate. The six distillates averaged 0.790 gram of formic acid with N/10 alkali, and 0.877 gram by Jones's method. These results establish that formic acid is the only volatile acid formed in the experiment, the higher value with permanganate resulting from traces of hydrogen sulphide or other reducing matter carried over in the distillation. Taking the first figures, 144 (138.8 grams of anhydrous sugar) grams of maltose gave 4.740 grams of formic acid.

Determination of Nonvolatile Acids, including Sugar, after Hydrolysis.—The above named residue of nonvolatile syrupy glucosido acids, weighing 132.8 grams, was hydrolyzed by heating under a reflux condenser on the boiling water bath for ten hours with 5 parts of 5 per cent. sulphuric acid. The theoretical amount of barium hydroxide for the removal of the acid was now added, the solution further boiled a half hour, and filtered. After preliminary titrations with Fehling's solution the filtrate was made up to definite volume of approximately one per cent. dextrose content, and accurately titrated for the sugar split off; 50 cc. of Fehling's solution required 24.75 cc. of the 5 liters of filtrate, corresponding to 0.2356 gram of dextrose, or a total of 48.40 grams for the original 132.8 grams of acids.

For the removal of the dextrose the solution was concentrated to 1 liter and boiled in a water bath for 10 hours with 50 grams of powdered calcium carbonate. Twenty-seven grams of undissolved carbonate of lime were filtered off; digestion of this with 5 per cent. acetic acid until there was no further action left an insoluble residue which was dissolved in hydrochloric acid and reprecipitated with ammonia. This gave 0.50 gram of white calcium oxalate; a previous experiment with the same quantities gave 0.9 gram.

Analysis of the salt, dried to constant weight at 100°, gave the following result: 0.4995 gram gave, on ignition, 0.1915 gram CaO.

	Calculated for $\text{CaC}_2\text{O}_4 \cdot \text{H}_2\text{O}$.	Found.
CaO	38.39	38.35

The aqueous solution of calcium salts and dextrose was concentrated in half-liter hemispherical evaporating dishes and alcohol was added slowly, with thorough stirring. The alcohol was decanted and the process repeated, the black, tarry lime salts being occasionally taken up in water and decolorized with animal charcoal, etc., until finally by precipitation and continued rubbing the salts became granular.¹ After drying they were repeatedly extracted with absolute alcohol until 0.5 gram showed no reduction on boiling with 10 cc. of Fehling's solution. The plate-dried lime salts weighed 107.75 grams and on analysis, by ignition, showed 15.21 per cent. of calcium oxide. The calcium was removed in the usual manner by treating the salts in a hot, dilute solution with a faint excess of oxalic acid. On distilling off the water from the filtrate under reduced pressure, finally heating for one-half hour on the boiling bath, a residue of 82.0 grams of syrupy, slightly mobile acids was obtained, which dissolved entirely in 1 liter of hot, absolute alcohol on long digestion. On concentrating this solution to about 500 cc. there were deposited in 24 hours 12.5 grams of mannonic lactone, melting at 148°-149°. By concentrating the mother liquor, etc., two further crops were obtained, so that finally a total of 22.2 grams of *d*-mannonic lactone were obtained, leaving a residue of 59.8 grams of nonvolatile gummy acids.

A portion of the mannonic lactone dissolved on digestion in 20 parts of absolute alcohol, and on cooling 80 per cent. of the material separated out in the form of light, flaky, snow-white needles. After four crystallizations from absolute alcohol the substance melted at 149°-152° and gave $[\alpha]_{20}^D = +51.5$.² $d = 1.034$; $p = 10.000$, *i. e.*, 1.7186 grams lactone and 15.4674 grams water. $(\alpha) = +5^\circ.34$ in a 1 dm. tube.

The substance gave no change of rotation on standing in water solution 24 hours, and all attempts to raise the specific rotation to that given by Fischer, $+54^\circ.8$, failed.³

Mannonic lactone dissolved in twice its weight of 50 per cent.

¹ E. Fischer: Ber. d. chem. Ges., **22**, 363.

² Fischer: Ber. d. chem. Ges., **22**, 3222. Nef: Ann. Chem. (Liebig), **357**, 270.

³ Cf. Nef: Ann. Chem. (Liebig), **357**, 271.

alcohol yields with an equal amount of phenylhydrazine, on standing 24 hours at room temperature, leafy crystals of the acid hydrazide, melting at 216° . It was also further identified by its conversion into the characteristic brucine salt which separates out from concentrated water solution on addition of alcohol in bulky, silky needles melting at 210° – 212° . The remaining 59.8 grams of nonvolatile, gummy acids were now resolved into three fractions, A, B and C, as follows: They were first dissolved in an equal weight of absolute alcohol, and twice the volume of ether was thereupon slowly added with much shaking. On standing overnight, decanting, and washing the residue with alcohol-ether (1 to 2 by volume) 26.1 grams of thick gum remained undissolved. The soluble portion, 33.8 grams, as well as the insoluble portion, gave on prolonged digestion with acetic ether a total of 25.8 grams of insoluble gum (C). The gums which dissolved in acetic ether were further resolved (after removing the solvent, etc.), by digestion, into an ether-soluble fraction, A, 11.1 grams, and a portion, B, 25.0 grams.

Fraction C (least soluble gums).—This fraction was titrated by the following method, which was uniformly used throughout the work where acids forming lactones were believed to be present. The material was dissolved in water and made up to a convenient volume and an aliquot portion containing about 0.5 gram gum was then taken for titration. This was considerably diluted with water and treated with an excess of N/10 sodium hydroxide for ten minutes on a boiling water bath. The end point was then determined by titrating back with N/10 hydrochloric acid and phenolphthalein as an indicator in all cases. Five-tenths gram of Fraction C required 20 cc. of N/10 alkali. Since half a gram of a hexonic acid lactone requires theoretically 28.07 cc. of N/10 alkali, some neutral material was present, as was shown by subsequent acylation of the fraction. On the basis of this titration the remaining aqueous solution of Fraction C was, however, first digested with the calculated amount, 40.7 grams, of brucine, a small amount of alcohol being added and the mixture boiled for 1 hour on a water bath after the alkaloid had

dissolved. Removal of the water under 20–30 mm. pressure, and finally heating to 80° gave a residue of gummy brucine salts weighing 67.3 grams. After dissolving this in half its weight of water, the subsequent addition of 5 parts of alcohol gave a rapid deposition of crystal needles of *d*-mannonic brucine, 15 grams, melting from 205° to 212°. These, on recrystallization, melted at 210°–212°. Since all attempts to obtain other crystalline brucine salts from the alcoholic filtrate still containing about 50 grams of salts failed, the mixture was converted back into free brucine and acids as follows: A dilute aqueous solution of the salts was treated with an excess, about 1.5 times the calculated amount, of aqueous sodium hydroxide. The precipitated brucine was filtered off and well washed and the remainder was removed from the aqueous filtrate by threefold extraction with chloroform. The filtered alkaline solution was then treated with slightly more than the theoretical amount of aqueous hydrochloric acid and the water removed at 20–30 mm., the solution being finally heated on a boiling water bath. The organic acids were then separated from the salt by thorough extraction with absolute alcohol. In this manner 16.5 grams of acid were finally recovered.

Fraction B.—Five-tenths of a gram of Fraction B, 25 grams, required on titration a total of 37.9 cc. of N/10 alkali; the calculated amount for 0.5 gram 1,2-dioxybutyrolactone is 42.37 cc. The remainder of the aqueous solution of Fraction B was consequently converted into salts by boiling with 76 grams of brucine. Fractional crystallization of the crude salts from small amounts of water and alcohol gave first 11.7 grams of *d*-mannonic brucine melting, after recrystallization, at 210°–212°. This salt can readily be separated from the other high-melting brucine salts of *d,l*-glycerinic, erythronic and threonic acids which may also possibly be present, especially in Fractions A and B, since it comes out very rapidly from hot concentrated aqueous solutions on addition of 4 to 5 volumes of hot alcohol. The 11.7 grams salt mentioned above, as well as the 15 grams of a corresponding salt referred to under Fraction C, were now proved to consist entirely of

d-mannonic lactone as follows: Twenty-four grams of the combined salts gave with sodium hydroxide, etc., 8 grams of crude acid gum (alcohol extract) from which, on crystallization from acetic ether, a total of 5 grams of the lactone melting from 145° – 148° was obtained. A portion of this, on further purification, gave crystals melting from 148° – 150° and showing a specific rotation of $+51.01$; *i. e.*, 2.0012 grams of substance and 18.0087 grams of water, $p = 10.001$; $d = 1.037$, found (α) in 1 dcm. tube, $+5.030$.

The portion of the 8 grams of crude lactone which still remained gummy, *i. e.*, about 3.0 grams, gave on treatment with 6 cc. of 50 per cent. alcohol and 3 cc. phenylhydrazine, after 24 hours at ordinary temperatures, 3.7 grams of practically pure *d*-mannonic phenylhydrazide melting from 210° to 216° .

The mother liquors from the above mentioned *d*-mannonic brucine gave, on long standing, a total of 51 grams of crystalline salts, in three crops, which melted from 170° to 205° ; and finally the 24.2 grams of gummy noncrystallizable salts left in the mother liquor gave with sodium hydroxide, etc., a total of 9.3 grams acid gum soluble in ethyl acetate. This was united with the corresponding lot, 16.5 grams, of acid gum recovered from Fraction C (see above), and the mixture then further resolved as in the first instance, by fractional precipitation with alcohol and ether, etc., into three fractions, C', 7.1 grams of alcohol extract, least soluble acid gum; B', 10.8 grams gum soluble in acetic ether; and A', 5.0 grams of ether-soluble gum.

Fraction C'.—This portion, 7.1 grams, contained some tar which was removed by acylation as follows: The gum was heated for nine hours at 95° – 100° with three parts of acetic anhydride; acetic acid and the excess of acetic anhydride were then removed by distillation at 20 mm. pressure, the flask was finally heated to 100° , and the residue of acylated gums taken up in hot ether, which left some insoluble tar. The acylated gums which had dissolved in the ether were then converted back into the unchanged free acids by threefold hydrolysis with three parts of water, heating for 9 hours at

100° and taking care to remove water and acetic acid after each operation by distilling at 20 mm. pressure and 100°, etc. Thus 4.4 grams of yellowish gum were recovered. Five-tenths of a gram of this required 29.6 cc. of N/10 sodium hydroxide on titration (the calculated amount for 0.5 gram hexonic acid lactone is 28.07 cc). Consequently, the remainder of the gum was converted into salts in the usual manner by digestion with 10 grams of brucine. Only one crop, 3.2 grams, of crystalline brucine salts melting at 125°–135° could be obtained from these by dissolving in alcohol, even on long standing, leaving a residue of 10.9 grams of gummy salts remaining after distillation under reduced pressure.

Fraction B'.—Five-tenths of a gram of Fraction B' (10.8 grams) required 30 cc. of N/10 sodium hydroxide for neutralization and therefore consisted mainly of hexonic acids. On treatment of the main portion with brucine, 38.3 grams of gummy salts were obtained which, on crystallization, yielded a total of 12.2 grams of crystalline salts melting from 125° to 145°. The remainder, 21.8 grams of gummy salts, was now united with the 10.99 grams of similar salts from C' (see above) and the whole converted by means of barium hydroxide, etc., back into 10 grams of gummy acids which obviously consisted of a mixture of hexonic acids, but which I did not succeed in separating into its components. Treatment with phenylhydrazine gave no crystallizable acid hydrazides.

Fraction A.—The first mentioned ether extract, A, 11.1 grams, was digested for 9 hours in dilute aqueous solution with 50 grams of finely ground strychnine, only 19.5 grams of the alkaloid dissolving. The gummy strychnine salts obtained after distilling off the water at 30 mm. pressure gave, after three crystallizations from absolute alcohol, a total of 17 grams of crude strychnine glycollate melting between 155° and 160°. The noncrystalline and easily soluble strychnine salts left, 18.5 grams, gave back with sodium hydroxide, etc., a total of 6.2 grams of acid gum (alcohol extract). Five-tenths of a gram of this required 39.0 cc. N/10 sodium hydroxide for neutralization (calculated for 1,2-di-

oxybutyrolactone, 42.37 cc.). The remainder gave, on digestion with 19 grams of brucine and subsequent fractional crystallization of the salts obtained, a total of 13.7 grams of brucine salts melting between 180° and 205° . Thirteen grams of easily soluble gummy salts remained which, when treated with barium hydroxide, etc., gave back 1.6 grams of acid gum. This, when converted into the strychnine salt, gave 1.2 grams more of crude strychnine glycollate melting between 150° – 160° , besides 5.8 grams of gummy, easily soluble salts which were united with a corresponding lot from Fraction A' (see below).

Fraction A'.—The second ether-soluble fraction of acid gums, 5.0 grams, took up, on boiling for 9 hours with an excess of strychnine, only 11.0 grams of the alkaloid, and fractional crystallization of the salts obtained gave in all only 2.5 grams of crude glycollic strychnine, melting between 150° and 160° . The remainder, 13.5 grams, was united with a corresponding lot of gummy strychnine salts, 5.8 grams, mentioned above under A. These gave with barium hydroxide, etc., 11.6 grams of strychnine and 5.6 grams of acid gum.

Glycollic Acid from Crude Strychnine Glycollate.—The total amount of crude glycollic strychnine obtained from Fractions A and A' was 20.6 grams; 17.0 grams of this salt gave, with sodium hydroxide, etc., 3.0 grams of syrupy acid (acetic ether extract), and from this by digestion in aqueous solution with an excess of powdered calcium carbonate, etc., 1.9 grams of crystallized calcium glycollate, $\text{Ca}(\text{C}_2\text{H}_3\text{O}_3)_2 \cdot 3\text{H}_2\text{O}$, were obtained. 0.4684 gram of the air-dried salt lost 0.1066 gram of water on drying to constant weight at 120° .

	Calculated for $\text{Ca}(\text{C}_2\text{H}_3\text{O}_3)_2 \cdot 3\text{H}_2\text{O}$.	Found.
H_2O	22.13	22.75

0.7500 gram of the anhydrous calcium salt gave 0.2198 gram of CaO on ignition.

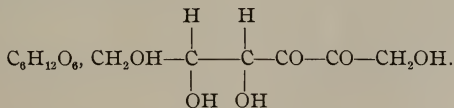
	Calculated for $\text{Ca}(\text{C}_2\text{H}_3\text{O}_3)_2$.	Found.
CaO	29.47	29.32

On the Nature of the Other Crystalline Brucine Salts Obtained.—The total amount of the various crystalline brucine salts (except *d*-mannonic brucine) obtained from the different fractions mentioned above, which had melting points varying from 125° to 205°, was 80.0 grams. These were combined and dissolved in 40 cc. hot water, and, on addition of 235 cc. of alcohol, crystals of a brucine salt melting between 180° and 190°, 21.5 grams in two crops, were obtained. Since this salt gave, on treatment with aqueous barium hydroxide, 15.4 grams of brucine and 4.6 grams of acid gum, the presence of glycerinic acid and of dioxybutyrolactone is probable but not yet established by what I have done.

*A New Hexonic Acid, α -Oxymethyl-*d*-ribonic Acid(?).*—The alcoholic mother liquors containing still about 56.5 grams of salts were found finally to give, on crystallization from 10 parts of 95 per cent. alcohol, 32.5 grams of transparent flat plates melting from 183° to 186°. These crystals are very sparingly soluble in cold water but dissolve in 10 parts of boiling water and on cooling at least 80 per cent. of the salt separates out in transparent plates. These properties are therefore so striking that this salt can very easily be separated from a mixture. The free acid obtained therefrom by aqueous sodium hydroxide, etc., and subsequent extraction of the salt residue with acetic ether, is a thick gum which gives, with an equal weight of phenylhydrazine in 2 parts of 50 per cent. alcohol, a crystalline phenylhydrazide which, on recrystallization from 50 per cent. aqueous alcohol, melts from 179° to 183°. This hydrazide was fairly difficultly soluble in cold water and practically insoluble in cold alcohol. The specific rotation of the hydrazide in 2 per cent. aqueous solution was found to be +8°.38. 0.4012 gram of the substance and 19.4591 grams of water, $p = 2.020$; $d = 1.004$; found α in a 1 dcm. tube = +0°.17. The acid gives apparently an insoluble basic barium salt since it is impossible to obtain it from its brucine salt by the usual method; *i. e.*, treatment with aqueous barium hydroxide. The resulting precipitate contains not only all the brucine, but practically all the acid in the form of an insoluble salt. I lost a considerable quan-

tity of material in this manner. Eleven grams of the brucine salt, when treated with sodium hydroxide, etc., gave 7 grams of brucine and on subsequent extraction of the salt residue with acetic ether 3.1 grams of thick acid gum were obtained. Five-tenths gram of this gum required 28.63 cc. N/10 sodium hydroxide for neutralization, where the calculated amount of N/10 alkali necessary for neutralizing 0.5 gram of a free hexonic lactone is 28.07 cc. These data prove that a hexonic acid must be present which is, however, not identical with any known hexonic acid. The calcium salt, made in the usual way from the acid gum, was found to crystallize from hot, concentrated aqueous solutions in small, translucent cubes which are very sparingly soluble in cold water. It was not analyzed, but gave in one per cent. aqueous solution a specific rotation of $+11^{\circ}.98$; 0.1786 gram substance and 17.6814 grams water, $p = 1.000$, $d = 1.001$, found α in a 1 dm. tube = $+0^{\circ}.12$.

Since Mr. Spoehr, as well as Mr. Rosario,¹ have obtained an analogous new hexonic acid, α -oxymethyl-*d*-arabonic acid—in the oxidation of alkaline solutions of dextrose and laevulose by air as well as by hydrogen peroxide, it is in the highest degree probable that my acid is α -oxymethyl-*d*-ribonic acid, which must be formed from maltose by a preliminary transformation² into dextrose-*d*-glucose which then gives the dextrose glucosone,



This by an asymmetric benzylic acid rearrangement then gives dextrose *d*- α -oxymethylribonic acid.

The alcoholic mother liquors from which the new hexonic acid brucine salt had been removed as thoroughly as possible still contained 25.2 grams gummy brucine salts which could not be obtained in crystalline form. These were, there-

¹ Work soon to be published in THIS JOURNAL.

² Lobry de Bruyn and Ekenstein: Rec. Trav. Chim., **16**, 258, 274. Nef: Ann. Chem. (Liebig), **357**, 297.

fore, decomposed with barium hydroxide into 16 grams of brucine and 9.0 grams of acid gum, indicating therefore, the presence of other hexonic acids.

Brief Summary of Results of Other Experiments with Maltose and Fehling's Solution.—An experiment with Fehling's solution on 144 grams maltose carried out in practically the same manner as given in detail above gave 133.7 grams of thick, syrupy glucosido acids which on hydrolysis gave 66.7 grams of gummy acids and 55.04 grams of dextrose. Forty-four and seven-tenths grams of the acids dissolved in acetic ether on thorough digestion, leaving, therefore, 22.2 grams of insoluble gum. The ethyl acetate solution deposited on standing 6.5 grams of crystallized mannonic lactone. On treating the gummy acids, 38.2 grams, recovered from the solvent, with 40 cc. alcohol and 38 cc. phenylhydrazine for 24 hours at ordinary room temperature, 9.45 grams of crystalline hexonic acid hydrazides melting from 204° to 206° separated out. On similar treatment with phenylhydrazine the 22.2 grams of gummy acids insoluble in acetic ether gave 25.5 grams of crystalline acid hydrazides. These combined hydrazides, 35 grams, gave on hydrolysis with 7 per cent. sodium hydroxide,¹ 13.05 grams of mannonic lactone, besides 5.5 grams of gummy acids. A portion of the latter when titrated with N/10 alkali gave results agreeing with those calculated for a free hexonic acid, and on converting the main portion of the gum with the calculated amount of brucine into salts (16.8 grams) there were obtained on fractional crystallization from aqueous alcohol 10.0 grams of mannonic brucine and 5.8 grams of the new so-called α -oxymethyl-*d*-ribonic brucine melting at 181° – 183° . This result indicates that *d*-gluconic acid cannot be present in any appreciable quantity. It must, however, be emphasized in this connection that treatment of the various fractions of the acid gums with phenylhydrazine and alcohol never removes the hexonic acids completely in the form of insoluble hydrazides. I obtained, for instance, in working up the acids forming alcohol-soluble hydrazides in the experiment just referred to above

¹ Nef: Ann. Chem. (Liebig), **357**, 225.

(by hydrolysis, etc.), a total of 21.0 grams of the very characteristic α -oxymethyl-*d*-ribonic brucine melting from 181° to 183°.

It is apparent, therefore, that the complete separation of the various hexonic acid hydrazides, which by themselves are practically insoluble in cold or hot absolute alcohol, is prevented to a considerable extent by the presence of the other acids which form alcohol-soluble hydrazides or phenylhydrazine salts.

Summarizing finally, there were obtained from 136.8 grams of anhydrous maltose in the reaction described in detail above 10.6 grams of carbon dioxide, 4.74 grams of formic acid, and 132.8 grams of nonvolatile gums consisting chiefly of glucosido acids. The latter gave on hydrolysis, besides 47.5 grams of dextrose, 82.35 grams of nonvolatile acids. A total of 45.02 grams of these acids was identified quantitatively as follows: 0.35 gram oxalic acid, 3.92 grams glycollic acid, 30.25 grams *d*-mannonic lactone, and 10.5 grams of a new hexonic acid called α -oxymethyl-*d*-ribonic acid. The nature of the remaining 37 grams unidentified acids was not established, mainly because of lack of time.

Experiments with a d-Maltosone and d-Glucosone.—It is extremely probable, from my results with maltose, that only two hexonic acids, namely, *d*-mannonic and α -oxymethyl-*d*-ribonic acid, are obtained in the hydrolysis of the glucosido acids which are formed by the action of Fehling's solution on maltose. In that case, both acids must be formed by an asymmetric benzylic acid rearrangement from 1,2-maltosone and 2,3-maltosone, respectively.¹ 1,2-*d*-Glucosone, which must be the common intermediate product when *d*-glucose, *d*-fructose, and *d*-mannose are oxidized by Fehling's solution, gives, on the other hand, by a partial asymmetric benzylic acid rearrangement, mainly *d*-gluconic acid and only small amounts of *d*-mannonic acid.²

It was, therefore, a point of great interest to prove the correctness of these conclusions by actually studying the

¹ Nef: Ann. Chem. (Liebig), **357**, 281 and 282.

² *Ibid.*, **357**, 284.

behavior of caustic alkalies towards *d*-glucosone as well as *d*-maltosone, substances which are now not so very difficult of access.¹ My preliminary experiments tend to confirm the correctness of the conclusions reached, but I regret to have to admit that the results are not absolutely final or decisive, and can only become so by a very careful repetition of the work with far larger quantities of material.

Experiments with Maltosone.—Maltosone was prepared from the osazone by the method of Emil Fischer and Armstrong.² One hundred and thirty grams of maltose gave, on treatment with aqueous phenylhydrazine acetate, 92.1 grams of maltosazone melting at 210°. On treating this, according to the directions, in 20-gram lots with benzaldehyde, I never obtained more than 11.0 grams of crude maltosone from 45 grams of osazone instead of the calculated 29.4 grams. That this poor yield is due chiefly to an incomplete hydrolysis of maltosazone under the conditions employed by Fischer and Armstrong was proved by subsequent experiments in which an almost quantitative yield was obtained by heating for 10 hours longer and treating a second time, after concentrating the aqueous filtrate to a small volume, with more benzaldehyde. Thus a mixture of 19 grams of maltosazone in 100 parts of boiling water gave finally, after 10 hours' heating on the boiling water bath with 1.5 parts of benzaldehyde, 11.9 grams of crude maltosone, instead of the calculated 12.4 grams. It is, of course, possible that some maltosone had been split into glucosone and dextrose on account of the prolonged heating with boiling water.

The crude maltosone prepared exactly according to Fischer and Armstrong's directions showed the following properties: (a) it gave on treatment in the cold with phenylhydrazine acetate an equal weight of maltosazone, crystallizing in rosettes, melting at 210°, and entirely free from the large, flat, needle-shaped crystals of *d*-glucosazone.³ (b) A solution of 0.2 gram of maltosone in 4 cc. of water, when added to 5 cc. of Fehling's solution, was markedly reduced in one minute, completely

¹ Ber. d. chem. Ges., **35**, 3141.

² Loc. cit.

³ J. Am. Chem. Soc., **25**, 1015. Grimbert: J. Pharm. Chim., **7**, 17-5.

in one-half hour in the cold. If, however, the maltosone was first dissolved in an alkaline tartrate solution, and this mixture allowed to stand 48 hours before the addition of the copper sulphate solution, the same conditions as to concentration and amounts being observed, only slight reduction to cuprous oxide was noticeable, approximately only 8 per cent. of that in the first experiment. (c) Cold solutions of 20 grams of maltosone in 400 cc. of water and of 18.5 grams of crystallized barium hydroxide in 200 cc. of water were mixed and allowed to stand for 48 hours. The calculated amount of sulphuric acid was then added to the dark red solution, which contained also a flocculent precipitate. In order to hydrolyze the supposed dextrose-*d*-mannonic acid formed, the filtrate was then made up to 1 liter with water, 50 grams of sulphuric acid added and the solution boiled five hours. The free sulphuric acid was now removed in the usual manner, care being taken to leave only a trace of barium in the solution. The water was removed by distillation under reduced pressure and the residue, 11.5 grams, was taken up in hot absolute alcohol. On standing, the characteristic crystals, 0.3 gram, of mannonic lactone separated out. These melted, on recrystallization from acetic ether, between 148° – 152° . The rest of the acid gum obtained, 11 grams, was resolved by solution in 20 cc. of alcohol and partial precipitation by addition of 40 cc. ether, into 2 fractions, *i. e.*, 4.8 grams soluble and 6.2 grams insoluble gum. The latter gave, on heating for 8 hours with 19 cc. acetic anhydride at 100° , 10.2 grams of acylated gum of which only 6.8 grams dissolved in hot ether. The latter, on fourfold hydrolysis with five parts of water, finally gave back 4.2 grams of acid gum. Twenty-five hundredths gram of this required 21.1 cc. of N/10 sodium hydroxide for neutralization. The remainder was then converted by means of 13.3 grams brucine into 18.5 grams gummy brucine salts. These gave, on fractional crystallization from alcohol, first 2 grams of crude *d*-mannonic brucine melting from 180° to 190° , which was converted by means of sodium hydroxide into the crystalline lactone melting at 145° – 148° , as well as its phenylhydrazide melting at 200° – 205° , and

second, 1.3 grams melting from 138° to 140° . This, on crystallization from 1.5 cc. water, gave transparent crystalline plates melting between 179° and 180° , and resembling very closely the so-called α -oxymethyl-*d*-ribonic brucine which I obtained from maltose by means of Fehling's solution. Finally, the gummy brucine salts left gave back 2.6 grams of acid gum which, on treatment with phenylhydrazine and alcohol, gave 1.2 grams of crystalline hydrazides melting from 185° to 195° .

Experiment with Glucosone.—Twenty-three and seven-tenths grams of crude maltosone, prepared according to the modified method given above from 38 grams of maltosazone, was hydrolyzed with 5 parts of 5 per cent. sulphuric acid for 5 hours in a boiling water bath. Considerable charring took place in this operation and on freeing the solution, first from sulphuric acid and then from water, 20 grams of a mixture of glucose and glucosone gum were obtained. This gave the following tests: Reduction took place at once with Fehling's solution in the cold. The presence of free glucose was shown by the production of gas with yeast suspension in the fermentation tube, since glucosone does not ferment with yeast.¹ One gram of the gum, when treated with phenylhydrazine acetate, gave rapidly, at room temperature, 0.5 gram of crystalline glucosazone, melting at 205° . The filtrate, on boiling with 0.5 gram of phenylhydrazine and 0.5 cc. of 50 per cent. acetic acid, gave a further crop of *d*-glucosazone, the presence of both 1,2-glucosone and *d*-glucose being thus indicated.² The remaining 18.5 grams of gum was now treated in the cold with one molecule of barium hydroxide, 17.2 grams, and 555 grams of water, giving therefore approximately the same concentration as was employed in the corresponding maltosone experiment described above, and set aside for 24 hours. Darkening and deposition of a flocculent precipitate was noticed and after removal of all but traces of the barium present, the water was distilled off under reduced pressure, a residue of 17.0 grams acid gum being

¹ Fischer and Armstrong: Ber. d. chem. Ges., **35**, 3144.

² E. Fischer: Ber. d. chem. Ges., **23**, 2121.

left. Three and seven-tenths grams of this which dissolved in ether were rejected and the remaining 13.3 grams gum were acylated in the usual manner, 21.8 grams of acylated gums being obtained, of which only 10.6 grams were soluble in hot ether, and fourfold hydrolysis of these with water at 100° gave finally 9.0 grams of acid gum. Five-tenths of a gram of the gum required 32.6 cc. of N/10 sodium hydroxide for neutralization (calculated for pentonic acid lactone, 33.8 cc). The remainder was then converted into brucine salts, which on crystallization by long standing gave finally 12.4 grams of crystalline salts melting from 135° to 145° . These gave back with sodium hydroxide, etc., 2.0 grams of acid gum, of which 0.5 gram, when treated with phenylhydrazine in aqueous alcohol solution, gave 9.5 grams of an acid hydrazide melting from 190° to 195° . The specific rotatory power of this in one per cent. solution was found to be $+12^{\circ}.27$; *i. e.*, 0.20 gram substance in 19.8 grams water, $p = 1.0$, $d = 1.002$, found α in 1 dm. tube = $+0^{\circ}.12$. This indicates the presence of *d*-gluconic acid since a known sample of *d*-gluconic hydrazide melting at 198° was found to give, in 2 per cent. aqueous solution, $[\alpha]_{\text{D}}^{20} = +13^{\circ}.0$.

The writer wishes to acknowledge his deep appreciation of the constant help and encouragement from Dr. Nef during the course of the above work.

UREIDES AND CYANAMIDES OF THE OXYFATTY ACIDS.

[SECOND PAPER.]

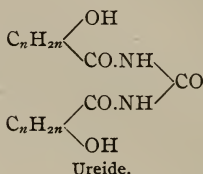
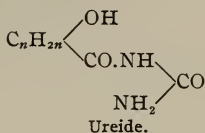
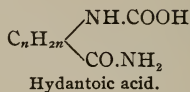
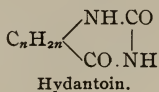
BY ERIK CLEMMENSEN AND ARNOLD H. C. HEITMAN.

In a previous paper¹ we pointed out that the real ureides of the oxyfatty acids, by which we understand urea in which one or more of the hydrogen atoms are replaced by the radicals

$\text{C}_n\text{H}_{2n} \begin{cases} \text{OH} \\ \text{CO—} \end{cases}$ of the oxyfatty acids up to that time had not been made. In contradistinction to the hydantoins and

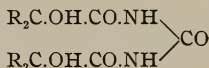
¹ THIS JOURNAL, 40, 280.

hydantoic acids these compounds still contain the characteristic alcoholic hydroxyl groups, and their nitrogen atoms are not linked directly to the C_nH_{2n} groups:



The results obtained in the above mentioned work, in which only the dialkyloxyacetic acids were investigated, may be briefly expressed as follows:

By treating the esters of the dialkyloxyacetic acids and urea with sodium alcoholate in alcoholic solution dialkyloxyacetylureides of the type



are formed, whereas by using thiourea or guanidine instead of urea in the above reaction, dialkyloxyacetylcyanamides,

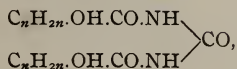


are obtained and not, as would be expected, the thioureides or guaneides. The dialkyloxyacetylcyanamides are converted by treatment with acids or alkalis into the dialkyloxyacetylureides.

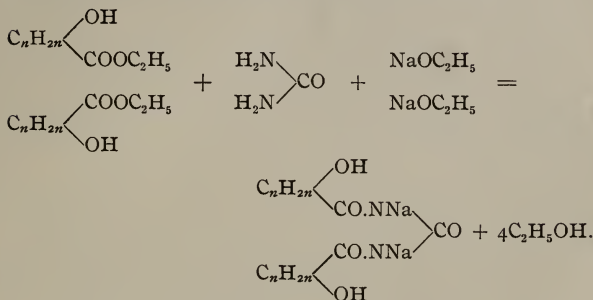
In this paper we have extended our investigation to the lower members of the α -oxyfatty acids, namely glycollic, lactic, α -oxybutyric and α -oxyisovaleric acids, and as we found their behavior in this respect perfectly analogous to that of

the dialkyloxyacetic acids, the results can be expressed in a general way as follows:

The ureides of the α -oxyfatty acids,



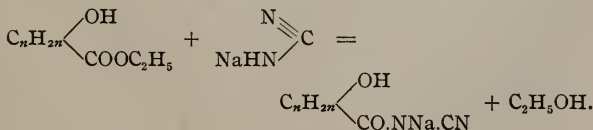
are formed by treating the esters and urea with alcoholic sodium alcoholate, the following reaction taking place:



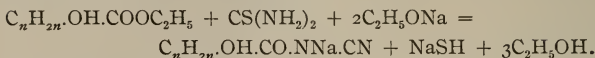
The new ureides are low-melting substances and act as rather strong dibasic acids.

The ureides of the type $\text{C}_n\text{H}_{2n}\cdot\text{OH}\cdot\text{CO}\cdot\text{NH}\cdot\text{CO}\cdot\text{NH}_2$, corresponding to urea in which only one hydrogen atom is replaced by the group $\text{C}_n\text{H}_{2n}\cdot\text{OH}\cdot\text{CO}-$, are not produced by this process.

By treating the esters of the α -oxyfatty acids and thiourea or guanidine with alcoholic sodium alcoholate the cyanamides $\text{C}_n\text{H}_{2n}\cdot\text{OH}\cdot\text{CO}\cdot\text{NH}\cdot\text{CN}$ are formed, but not the thioureides or guaneides, as would be expected. In this case the sodium alcoholate apparently converts the thiourea and guanidine into sodium cyanamide, which in turn reacts with the esters as follows:

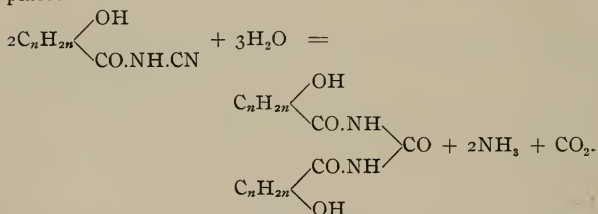


The whole reaction which takes place on treating a mixture of the esters of the α -oxyfatty acids and thiourea with sodium alcoholate is therefore as follows:



The reaction is quite interesting in view of the fact that the malonic esters¹ and the alkyl substituted malonic esters² under the same conditions yield the thioureides and guaneides, and seems to be typical for the α -oxyfatty acids.

The new cyanamides are high-melting, well crystallizing substances, which on boiling with dilute acids (for instance, 10 per cent. sulphuric acid) are quantitatively converted into the above mentioned ureides, the following reaction taking place:



Some interesting by-products are obtained by the action of sodium alcoholate on the esters and thiourea, as small quantities of thiocyanates of the α -oxyfatty acids, $\text{C}_n\text{H}_{2n}\cdot\text{OH}\cdot\text{CO}\cdot\text{S}\cdot\text{CN}$, always seem to be formed.

Now acyl thiocyanates apparently have not been made before. Dixon and Doran have shown³ that lead thiocyanate, when treated with acid chlorides, yields acyl thiocarbimides $\text{R}\cdot\text{CO}\cdot\text{NCS}$ and not the acyl thiocyanates $\text{R}\cdot\text{CO}\cdot\text{S}\cdot\text{CN}$, as would be expected, and that Michael's acetyl and butyryl thiocyanate⁴ really are the isomeric thiocarbimides. Dixon, therefore, concludes that acyl thiocyanates are not yet known.⁵

¹ Michael: J. prakt. Chem., [2] **35**, 456.

² Fischer and Dilthey: Ann. Chem. (Liebig), **335**, 334.

³ J. Chem. Soc., **67**, 575.

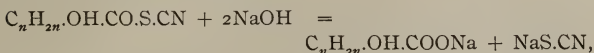
⁴ Ann. Chim. Phys., [5] **11**, 295, 300.

⁵ J. Chem. Soc., **93**, 684.

The acyl thiocarbimides are pungent, very reactive liquids which are immediately decomposed by cold water and some of which are so unstable that all efforts to isolate them have been in vain.

Now the compounds obtained by us in the above mentioned process have quite other properties, as they are stable, crystalline substances, which can be boiled with water and dilute acids without decomposition.

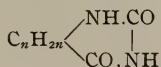
It is therefore out of question to regard them as acyl thiocarbimides, and as they have the right empirical formula, and on boiling with alkali hydroxides yield salts of thiocyanic acid and of the oxyfatty acids,



there is every reason to consider them as thiocyanates of these acids.

They thus represent the first known acyl thiocyanates and we therefore have decided to make a closer investigation of them, possibly including some of the other fatty acids, and to publish the results in a later paper.

In the literature and text-books it is a common mistake to designate the compounds having the formula



as ureides of the oxyfatty acids although they lack the presence

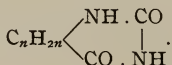
of the radical $\text{C}_n\text{H}_{2n} \begin{cases} \text{OH} \\ | \\ \text{CO}- \end{cases}$ which certainly should be a necessary requirement for these compounds and we have, strange to say, not been able to find any contradiction to this nomenclature, although the ureides almost everywhere clearly are defined as substitution products of urea with acid radicals.

For instance the compound $\text{CH}_2 \begin{cases} \text{NH}.\text{CO} \\ | \\ \text{CO}.\text{NH} \end{cases}$ is called glycolylurea notwithstanding that it does not contain the glycolyl

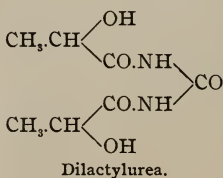
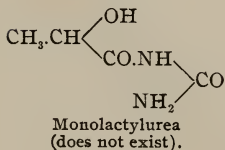
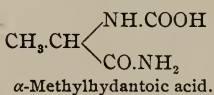
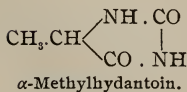
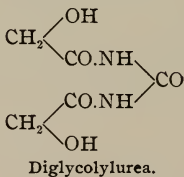
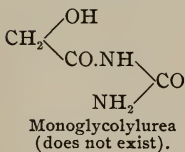
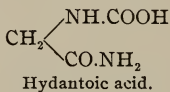
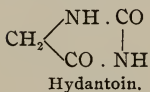
(oxyacetyl) group $\text{CH}_2 \begin{matrix} \diagup \text{OH} \\ \diagdown \text{CO—} \end{matrix}$, for to follow Dixon¹ and

call the group $\text{—CH}_2\text{.CO—}$ glycolyl would certainly be contrary to all established rules of nomenclature. It would be more consistent to reserve the term ureides of the oxyfatty acids

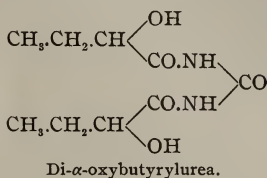
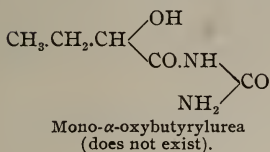
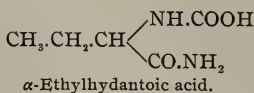
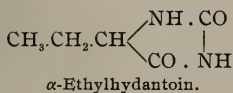
for ureas containing the group $\text{C}_n\text{H}_{2n} \begin{matrix} \diagup \text{OH} \\ \diagdown \text{CO—} \end{matrix}$ and retain the name hydantoin for those with the formula



The nomenclature of the first members of these series would therefore be as follows:



¹ J. Chem. Soc., 71, 637.



We had considerable trouble in preparing the esters of the α -oxyfatty acids in sufficient quantities, as the different methods described in the literature gave very unsatisfactory yields, until a paper on esterification by Bogojawlensky and Narbutt¹ helped us to overcome our difficulties. They recommend that esterifications be carried out by boiling the acids and alcohols with anhydrous copper sulphate, and have applied this method to a large number of acids with excellent results. By dehydrating the copper sulphate a small quantity of sulphuric acid anhydride is formed, and this seems to accelerate the esterification, and they further show that the yield of esters in many cases can be improved by adding small amounts of sulphuric acid.

In order to determine whether this method was suitable for preparing the esters of the α -oxyfatty acids (Bogojawlensky and Narbutt have tried it only on acids which can be esterified with sulphuric or hydrochloric acid) we boiled the respective acids, dissolved in excess of absolute alcohol, with anhydrous copper sulphate with and without an addition of sulphuric acid. The results were however not good, as the sulphuric acid decomposed in great part the esters formed, when we tried to distil them off.

It was only when no sulphuric acid was used and the copper sulphate was dehydrated at so low a temperature that no decomposition took place, that we obtained good yields of the esters. The operation was carried out as follows:

¹ Ber. d. chem. Ges., **38**, 3344.

The dried acid was dissolved in commercial absolute alcohol and boiled with anhydrous copper sulphate for about 24 hours. In dehydrating the copper sulphate care must be taken to do it at as low temperature as possible, so that no decomposition, with formation of sulphuric acid anhydride, takes place. The reaction product was then filtered, the alcohol distilled off and the ester rectified.

The yield was good for all four acids, and the method seems to be especially adapted to the preparation of esters easily decomposed by water, which is the case with most of the esters of the oxyfatty acids, and to be able to displace the more or less tedious processes now in use for the preparation of these esters.

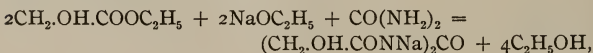
Thus the operations consisting in (1) heating the potassium or silver salts with alkyl iodides, (2) heating the halogen substituted fatty acids with sodium acetate and absolute alcohol, and (3) heating the anhydrides with absolute alcohol all require to be carried out under pressure, while another method much used, distillation of the calcium salts with potassium alkyl sulphate, gives very unsatisfactory yields.

EXPERIMENTAL.

$$\begin{array}{l} \text{CH}_2\text{OH.CO.NH} \\ \text{Diglycolylurea,} \quad \left. \begin{array}{l} \text{CH}_2\text{OH.CO.NH} \end{array} \right\} \text{CO.—The ethyl glycollate} \end{array}$$

was made by boiling 100 grams glycollic acid and 200 grams commercial absolute alcohol with 75 grams anhydrous copper sulphate for 24 hours. The copper sulphate was then filtered off, and the ester rectified; yield, 95 grams ester boiling at 158°–160°.

In order to make the glycolylurea, 3 grams sodium were dissolved in 100 cc. absolute alcohol, and to the cooled solution were added 8 grams urea and 20.8 grams ethyl glycollate. The calculated amount of sodium, corresponding to two atoms sodium for two molecules ester, is 4.6 grams,



but it was found that the smaller amount of sodium gave better results.

The whole was boiled in a flask with return condenser for two hours. Most of the alcohol was then distilled off, the remainder containing the sodium salt of the glycolylurea allowed to cool and carefully acidified with dilute acetic acid (10 per cent.). The rest of the alcohol was then distilled off and the remaining liquid extracted with ether several times. After evaporation of the ether the ureide remained as an oil, which on standing a short time solidified to a radiated crystalline mass. The substance was dissolved in boiling benzene, from which it crystallized in colorless, very irregular, thin plates melting at 88° – 89° and this melting point was not changed by a further recrystallization. The yield was 7 grams or about 40 per cent. of the theoretical.

0.2599 gram substance gave 0.3301 gram CO_2 and 0.0985 gram H_2O .

0.2956 gram substance gave 43.5 cc. N at 25° and 741 mm.

	Calculated for $\text{C}_5\text{H}_8\text{O}_5\text{N}_2$.	Found.
C	34.07	34.64
H	4.58	4.22
N	15.91	15.99

Diglycolylurea can also be made by boiling glycolylcyanamide (see below) with dilute sulphuric acid.

Five grams glycolylcyanamide were boiled for fifteen minutes with 100 cc. dilute sulphuric acid (10 per cent.) and the ureide formed shaken out with ether several times. After evaporation of the ether a colorless oil remained which on standing solidified to a white radiated crystalline mass weighing 4.1 grams, which is about 93 per cent. of the theoretical. Crystallized from boiling benzene it melted at 88° .

Diglycolylurea is very easily soluble in water, alcohol, ether and chloroform, slightly soluble in cold benzene, more so in warm benzene and nearly insoluble in petroleum ether. Carefully heated in a test tube it boils without decomposition, condensing further up in the tube in the form of a liquid, which on cooling solidifies to a crystalline mass. It is not

decomposed by boiling carbonates and dilute acids but decomposition takes place, with evolution of ammonia, on boiling with alkali hydroxides even in very dilute solution. It acts as a quite strong dibasic acid, which even in the cold decomposes the alkali, and the alkali-earth carbonates, forming very soluble salts.

The silver salt is best prepared by precipitating a solution of alkali ureide with silver nitrate. Recrystallized from boiling water it forms long silky needles. It is almost insoluble in cold water and alcohol, more soluble in boiling alcohol, from which it crystallizes in long monoclinic prisms, and quite readily soluble in warm water.

Air-dried, it contains 2.5 molecules water of crystallization, which it does not lose *in vacuo* over sulphuric acid.

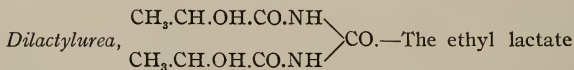
0.2978 gram substance gave 0.1479 gram Ag.

	Calculated for $C_8H_6O_5N_2Ag_{2.25}H_2O$.	Found.
Ag	49.61	49.67

At 100° the salt loses one molecule water.

0.2455 gram substance gave 0.1273 gram Ag.

	Calculated for $C_5H_6O_5N_2Ag_2 \cdot 1.5H_2O$.	Found.
Ag	51.76	51.85



was made as follows: One hundred grams lactic acid (75 per cent.) were dried on the steam bath for 48 hours, then mixed with 200 cc. commercial absolute alcohol and 75 grams anhydrous copper sulphate and boiled for 24 hours. The rectified ester boiled at 153°–155°. Yield, 70 grams. Three grams sodium were dissolved in 100 cc. absolute alcohol and to the cooled solution were added 8 grams urea and 23.6 grams ethyl lactate and the whole boiled for two hours. The reaction product was freed from most of the alcohol, then cooled, carefully acidified with dilute acetic acid (10 per cent.) and, after the rest of the alcohol had been distilled off, extracted with ether several times. After evaporation of the ether the

dilactylurea remained as an almost colorless oil. On standing *in vacuo* over sulphuric acid it slowly solidified to a somewhat soft, crystalline mass. Sometimes it would not crystallize at all even on standing for weeks but crystallization could always be effected by contact with a crystal already formed.

The substance no doubt contained impurities, especially lactic acid, and as we were not able to crystallize it from any solvent, we tried to purify it through one of the salts. By investigating these we found that the ureide on boiling with zinc oxide yields a zinc salt which is practically insoluble in boiling water, and as zinc lactate is easily soluble in warm water, this salt is well adapted for purifying the substance. The ureide was therefore dissolved in water, the solution boiled with an excess of zinc oxide, and the precipitated zinc salt collected and washed thoroughly with hot water. It was then dissolved in dilute sulphuric acid (25 per cent.), and the solution extracted several times with ether. After evaporation of the ether, the ureide remained as a colorless oil, which on standing solidified to a crystalline mass of small needles, appearing under the microscope as pointed rhombic prisms. When heated the ureide begins to soften at 47° and melts at 49° – 50° .

0.3361 gram substance gave 0.5033 gram CO_2 and 0.1690 gram H_2O .

0.2919 gram substance gave 36.3 cc. N at 25° and 746 mm.

	Calculated for $\text{C}_7\text{H}_{12}\text{O}_5\text{N}_2$.	Found.
C	41.15	40.84
H	5.93	5.60
N	13.73	13.61

Dilactylurea may also be made by boiling lactylcyanamide (see below) with dilute sulphuric acid. Five grams lactylcyanamide were boiled for fifteen minutes with 100 cc. sulphuric acid (10 per cent.) and the cooled solution extracted with ether. The ureide was then obtained as a colorless oil which on standing solidified to a crystalline mass of small needles. It began to soften at 47° and melted at 49° – 50° . The yield was 4.2 grams, which is practically the theoretical.

Dilactylurea is very easily soluble in water, alcohol, ether and chloroform, quite readily soluble in boiling benzene, from which it separates as an oil on cooling, and nearly insoluble in petroleum ether. It is not decomposed by boiling with alkali carbonates or dilute acids but on warming with alkali hydroxides ammonia is given off. When the substance is carefully heated in a test tube it boils without decomposition. Like glycolylurea it acts as a dibasic acid, which even in the cold acts on the alkali and alkali-earth carbonates, forming very soluble salts.

When copper chloride is added to an excess of concentrated solutions of calcium, barium, strontium or magnesium salts of lactylurea, double salts of the formula $C_{14}H_{20}O_{10}N_4CuM$ ($M = Ca, Ba, Sr$ or Mg) are precipitated as ultramarine-blue bodies, which are slightly soluble in water and insoluble in alcohol. They are readily soluble in excess of copper chloride and on boiling these solutions bright green precipitates of basic copper salts are formed.

For analysis the calcium copper salt was dried at 100° .

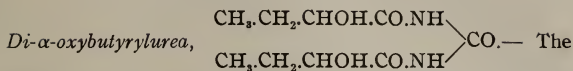
1.1840 gram substance gave 0.1833 gram Cu_2S and 0.1290 gram CaO .

	Calculated for $C_{14}H_{20}O_{10}N_4CaCu$.	Found.
Cu	12.52	12.36
Ca	7.90	7.78

The silver salt is obtained in the same way as silver glycolylurea and crystallizes from warm water in groups of small needles which under the microscope appear as monoclinic prisms. It is very sparingly soluble in cold water and alcohol, slightly soluble in boiling alcohol, and quite readily soluble in warm water. Dried in the air or *in vacuo* over sulphuric acid it contains 1.5 molecules water of crystallization, which it does not lose at 100° .

0.2050 gram substance gave 0.0996 gram Ag.

	Calculated for $C_7H_{10}O_5N_2Ag_2 \cdot 1.5H_2O$.	Found.
Ag	48.50	48.59



ethyl α -oxybutyrate we used was made by boiling 100 grams α -oxybutyric acid and 200 cc. commercial absolute alcohol with 75 grams anhydrous copper sulphate for 12 hours. The average yield of ester was 95 grams. Boiling point, 165° .

In preparing the α -oxybutyric acid we used the method of Markownikow¹ as modified by Bischoff and Walden,² which consists in boiling α -brombutyric acid with potassium carbonate. The α -brombutyric acid was made by brominating butyric acid according to the directions of Genvresse.³

The ureide was made in the usual way. Four grams sodium were dissolved in 100 cc. absolute alcohol and to the cooled solution were added 8 grams urea and 26.4 grams ethyl α -oxybutyrate and the whole boiled for three hours. Most of the alcohol was then distilled off, the remainder acidified with dilute acetic acid (10 per cent.), the rest of the alcohol distilled off, and the ureide shaken out with ether. The ether solution yielded on evaporation a faintly yellow oil, which *in vacuo* over sulphuric acid solidified to a crystalline mass. The yield was 17 grams impure ureide, which is about 73 per cent. of the theoretical.

As we did not succeed in crystallizing the substance from a solvent, it was purified through the silver salt. The ureide was dissolved in the equivalent amount of sodium carbonate and precipitated with silver nitrate. The silver salt was washed with water, recrystallized from boiling water and decomposed with hydrogen sulphide. The filtrate from the silver sulphide was extracted with ether, and the ether evaporated, whereupon the ureide remained as a colorless oil, which on standing solidified to a mass of short prismatic crystals. Under the microscope they appeared as stout, rhombic prisms. The ureide melts at 48° – 49° and begins to soften at 46° .

¹ Ann. Chem. (Liebig), **153**, 242.

² *Ibid.*, **279**, 104.

³ Bull. Soc. Chim., [3] **7**, 364.

0.2291 gram substance gave 0.3904 gram CO_2 and 0.1351 gram H_2O .

0.2089 gram substance gave 22.8 cc. N at 27° and 745 mm.

	Calculated for $\text{C}_9\text{H}_{16}\text{O}_6\text{N}_2$.	Found.
C	46.52	46.47
H	6.95	6.57
N	12.07	11.80

Di- α -oxybutyrylurea can also be made by boiling α -oxybutyrylcyanamide (see below) with dilute sulphuric acid. Five grams oxybutyrylcyanamide were boiled with 100 cc. sulphuric acid (10 per cent.) for fifteen minutes and the ureide shaken out with ether. It was then obtained as a colorless oil which on standing solidified to a mass of stout rhombic prisms melting at 48° – 49° . The yield was practically the theoretical.

Di- α -oxybutyrylurea is easily soluble in water, alcohol and ether, quite readily soluble in benzene and almost insoluble in petroleum ether. It is not decomposed on boiling with carbonates and dilute acids, but decomposition takes place on warming with alkali hydrates with evolution of ammonia.

Like the other ureides of this class it acts as a quite strong dibasic acid, yielding soluble salts with alkali and alkali-earth carbonates.

Solutions of calcium, barium, strontium and magnesium salts of the ureide give with copper chloride precipitates of the characteristic blue double salts of the formula $\text{C}_{18}\text{H}_{28}\text{O}_{10}\text{N}_4\text{CuM}$, which are but slightly soluble in water and dissolve in excess of copper chloride.

The silver salt is obtained in the usual way and crystallizes from warm water in groups of small monoclinic needles. Dried in the air and *in vacuo* over sulphuric acid it contains 1.5 molecules water of crystallization, which it does not lose at 100° .

0.2178 gram substance gave 0.0990 gram Ag.

	Calculated for $\text{C}_9\text{H}_{14}\text{O}_6\text{N}_2\text{Ag}_2 \cdot 1.5\text{H}_2\text{O}$.	Found.
Ag	45.62	45.46

Di- α -oxyisovalerylurea,
$$\begin{array}{c} (\text{CH}_3)_2\text{CH}.\text{CHOH}.\text{CO}.\text{NH} \\ (\text{CH}_3)_2\text{CH}.\text{CHOH}.\text{CO}.\text{NH} \end{array} \text{CO},$$
 was

made as follows: Four grams sodium were dissolved in 100 cc. absolute alcohol and boiled with 8 grams urea and 29.2 grams ethyl α -oxyisovalerate for three hours. Most of the alcohol was then distilled off and the remaining liquid acidified with acetic acid (10 per cent.). After evaporation of the rest of the alcohol the ureide on cooling separated out as an oil. It was redissolved in boiling water and then obtained as a colorless oil boiling at 277° – 279° at ordinary pressure, and having a specific gravity at 15° of 1.1922. The yield was 22 grams, which is about 85 per cent. of the theoretical.

0.2304 gram substance gave 0.4239 gram CO_2 and 0.1523 gram H_2O .

0.1823 gram substance gave 18.2 cc. N at 26° and 746 mm.

	Calculated for $\text{C}_{11}\text{H}_{20}\text{O}_5\text{N}_2$.	Found.
C	50.73	50.18
H	7.75	7.36
N	10.77	10.87

Di- α -oxyisovalerylurea can also be made by treating α -oxyisovalerylcyanamide (see below) with dilute sulphuric acid. Five grams oxyisovalerylcyanamide were boiled with 100 cc. sulphuric acid (10 per cent.) for half an hour and the solution extracted with ether. After evaporation of the ether the ureide remained as a colorless oil which could not be brought to crystallization even on standing for weeks *in vacuo* over sulphuric acid. The yield was practically quantitative.

0.1531 gram substance gave 0.2825 gram CO_2 and 0.1019 gram H_2O .

0.1215 gram substance gave 12.2 cc. N at 26° and 746 mm.

	Calculated for $\text{C}_{11}\text{H}_{20}\text{O}_5\text{N}_2$.	Found.
C	50.73	50.32
H	7.75	7.42
N	10.77	10.93

The ureide is sparingly soluble in cold water, readily soluble in warm water and very easily soluble in alcohol and ether.

It dissolves quite readily in benzene and only slightly in petroleum ether. It dissolves easily in alkali carbonates and is precipitated from these solutions on addition of acids. It is decomposed on boiling with alkali hydrates even in very dilute solution, but it can be boiled with dilute acids and alkali carbonates without decomposition. The double salts $C_{22}H_{36}O_{10}N_4CuM$ (where $M = Ca, Ba, Sr$ or Mg) are made by boiling the ureide with excess of the alkali-earth carbonates and precipitating from the concentrated filtrate with copper chloride. They are then obtained as ultramarine-blue substances which are almost insoluble in water and readily dissolve in excess of copper chloride.

For analysis the calcium copper salt was dried at 100° .

0.9975 gram substance gave 0.1285 gram Cu_2S and 0.0891 gram CaO .

	Calculated for $C_{22}H_{36}O_{10}N_4CaCu$.	Found.
Cu	10.25	10.28
Ca	6.47	6.38

The silver salt can be made by precipitating a solution of alkali ureide with silver nitrate. Recrystallized from boiling water it forms small slender monoclinic needles. It is slightly soluble in cold water, much more so in warm water and dissolves readily in cold alcohol.

Air-dried the salt contains 2.5 molecules water of crystallization.

0.2703 gram substance gave 0.1120 gram Ag .

	Calculated for $C_{11}H_{18}O_5N_2Ag_2 \cdot 2.5H_2O$.	Found.
Ag	41.58	41.44

On standing *in vacuo* over sulphuric acid this salt loses one molecule water of crystallization and the remaining 1.5 molecules are retained at 100° .

0.2993 gram substance gave 0.1291 gram Ag .

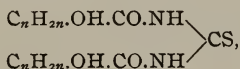
	Calculated for $C_{11}H_{18}O_5N_2Ag_2 \cdot 1.5H_2O$.	Found.
Ag	43.07	43.13

The ethyl α -oxyisovalerate we used was made in our usual way by boiling 100 grams α -oxyisovaleric acid and 200 cc. absolute alcohol with 50 grams anhydrous copper sulphate for 12 hours. The yield was about 100 grams. The rectified ester boiled at 174° – 176° .

The α -oxyisovaleric acid was made from α -bromisovaleric acid by the same method we used for making α -oxybutyric acid.

Cyanamides of the α -Oxyfatty Acids, $C_nH_{2n}.OH.CO.NH.CN$.—

As already mentioned, these compounds were obtained by a process which we expected would yield the thioureides,



namely, by heating the esters of the α -oxyfatty acids and thiourea with alcoholic sodium alcoholate.

Glycolylcyanamide, $CH_2.OH.CO.NH.CN$, was made as follows: Two grams sodium were dissolved in 100 cc. absolute alcohol and to the cooled solution were added 9 grams thiourea and 10.4 grams ethyl glycollate. The whole was boiled for one hour. Most of the alcohol was then distilled off, and to the cooled remainder was added exactly as much dilute acetic acid (20 per cent.) as was necessary to bind all the sodium. On standing in a cool place the glycolylcyanamide crystallized out. It was washed with alcohol and dissolved in boiling alcohol, from which it crystallized in large shining monoclinic prisms. The yield was 6 grams, which is 60 per cent. of the theoretical. On being heated it began to decompose at 217° and was entirely melted at 237° .

0.3386 gram substance gave 0.4487 gram CO_2 and 0.1247 gram H_2O .

0.2308 gram substance gave 60.2 cc. N at 27° and 740 mm.

	Calculated for $C_3H_4O_2N_2$.	Found.
C	35.98	36.14
H	4.03	4.10
N	28.01	28.00

Glycolylcyanamide is quite readily soluble in cold water, less so in cold alcohol. It dissolves readily in warm alcohol and very easily in warm water. It is almost insoluble in ether, benzene and petroleum ether. It dissolves easily in cold alkali hydroxides and is precipitated on addition of acids if the solutions are concentrated enough, but redissolves in excess of these. On boiling with acids (for instance, 10 per cent. sulphuric acid) it is quantitatively converted into diglycolylurea. The same transformation no doubt at first takes place on boiling with alkali hydroxides, but in this case the ureide formed is also decomposed.

Glycolyl Thiocyanate, $\text{CH}_2\text{OH.CO.S.CN}$.—The mother liquid from the glycolylcyanamide was extracted with ether several times, and the ether evaporated. A yellow oil remained, in which, on standing *in vacuo* over sulphuric acid, some long needles crystallized out. Dry ether dissolved the oil, while the needles remained undissolved. They were recrystallized from a little warm water and then obtained as stout short prisms melting at $171^\circ\text{--}172^\circ$. After being melted the substance gave with ferric chloride the deep red color characteristic for rhodanates. It was thus nothing but thiourea. The oil was freed from ether. On standing it solidified to a yellow crystalline mass, which was dissolved in a large amount of boiling benzene. On cooling, the solution deposited a little thiourea. It was filtered and concentrated, whereupon a substance crystallized out in groups of small slender yellow needles. Once more recrystallized from boiling benzene, it melted constant at 106° .

The substance contained sulphur. Its aqueous solution was not colored red by ferric chloride, but after being boiled with sodium hydroxide and then carefully acidified, a deep red color was produced by addition of ferric chloride. When the substance was boiled with sodium hydroxide, acidified and then extracted with ether an oil was obtained, which was identified as glycollic acid. These reactions would indicate that the substance was glycolyl thiocyanate, $\text{CH}_2\text{OH.CO.S.CN}$, and a nitrogen and sulphur determination confirmed

this assumption, although we had not enough material to make a complete analysis.

0.0682 gram substance gave 7.7 cc. N at 28° and 750 mm.

0.0890 gram substance gave 0.1770 gram BaSO₄.

	Calculated for C ₈ H ₃ O ₂ NS.	Found.
N	11.96	12.22
S	27.39	27.34

Glycolyl thiocyanate is easily soluble in water, alcohol and ether, readily soluble in warm benzene, less so in cold, and nearly insoluble in petroleum ether.

Lactylcyanamide, CH₃.CH.OH.CO.NH.CN. — Unlike the other cyanamides of this class this compound is already known, as it was obtained by Merting¹ by adding lactide to a concentrated alcoholic solution of potassium cyanamide.

We made it in the following way: Two grams sodium in 100 cc. absolute alcohol were boiled for one hour with 9 grams thiourea and 11.8 grams ethyl lactate. Most of the alcohol was then distilled off and to the cooled residue was added exactly as much acetic acid (20 per cent.) as was necessary to bind all the sodium. On standing, the lactylcyanamide crystallized out. It was recrystallized from boiling alcohol, from which it separated out in groups of small flat needles. The yield was 8 grams, which is about 70 per cent. of the theoretical. The substance begins to soften at 208° and melts at 212°.

0.1362 gram substance gave 0.2103 gram CO₂ and 0.0619 gram H₂O.

0.0915 gram substance gave 21.0 cc. N at 28° and 746 mm.

	Calculated for C ₄ H ₆ O ₂ N ₂ .	Found.
C	42.08	42.11
H	5.30	5.06
N	24.56	24.71

Lactylcyanamide is quite readily soluble in cold water, much less so in cold alcohol. It dissolves readily in boiling alcohol and still more easily in warm water from which it

¹ J. prakt. Chem., [2] 17, 31.

crystallizes in plates in groups resembling cauliflower. It is nearly insoluble in ether, benzene and petroleum ether. It dissolves very easily in cold alkali hydroxides and is precipitated on adding acids if the solutions are not too dilute, but redissolves in excess of these. On boiling with acids (for instance 10 per cent. sulphuric acid) it is quantitatively converted into dilactylurea.

Lactyl Thiocyanate, $\text{CH}_3\text{CH.OH.CO.S.CN}$.—The mother liquid from the lactylcyanamide, which contained small quantities of lactyl thiocyanate, was extracted with ether several times and the ether evaporated. A yellow oil was obtained which on standing solidified to a crystalline mass. This was dissolved in anhydrous ether, whereby a little thiourea was left undissolved, the ether evaporated and the residue dissolved in boiling benzene. On standing, the substance crystallized out in groups of small colorless needles. Recrystallized again from benzene it melted constant at $89^\circ\text{--}90^\circ$.

0.1834 gram substance gave 0.2437 gram CO_2 and 0.0595 gram H_2O .

0.1668 gram substance gave 16.6 cc. N at 27° and 737 mm.

0.1058 gram substance gave 0.1902 gram BaSO_4 .

	Calculated for $\text{C}_4\text{H}_5\text{O}_2\text{NS}$.	Found.
C	36.61	36.24
H	3.84	3.61
N	10.68	10.64
S	24.46	24.71

Lactyl thiocyanate is easily soluble in water, alcohol and ether, only sparingly soluble in cold benzene, more so in boiling benzene and almost insoluble in petroleum ether. Its aqueous solution is not colored red by ferric chloride even after boiling with dilute acids but on warming with alkali hydroxides it is decomposed into thiocyanic acid and lactic acid.

As already mentioned these thiocyanates represent the first known acyl thiocyanates, and we will therefore return to them in a later paper in which will be included the α -oxybutyryl and α -oxyisovaleryl thiocyanates.

α -Oxybutyrylcyanamide, $\text{CH}_3\text{CH}_2\text{CHOH.CO.NH.CN}$, was

made as follows: Two and two-tenths grams sodium were dissolved in 100 cc. absolute alcohol and to the cooled solution were added 9 grams thiourea and 13.2 grams ethyl α -oxybutyrate and the whole boiled for one hour. The alcohol was then distilled off as completely as possible and to the cooled residue was added just enough acetic acid (10 per cent.) to combine with all the sodium. On standing, the α -oxybutyrylcyanamide separated out. It was washed with a little cold water and dissolved in boiling water, from which it crystallized in groups of thin shining plates. The yield was 9 grams, which is about 70 per cent. of the theoretical. The substance began to soften at 205° and melted at 207° – 208° .

0.1689 gram substance gave 0.2907 gram CO_2 and 0.0930 gram H_2O .

0.1612 gram substance gave 32.8 cc. N at 26° and 736 mm.

	Calculated for $\text{C}_5\text{H}_8\text{O}_2\text{N}_2$.	Found.
C	46.84	46.94
H	6.30	6.13
N	21.88	21.84

α -Oxybutyrylcyanamide is only slightly soluble in cold water, more so in hot water, from which it crystallizes in plates. It is quite readily soluble in cold alcohol and easily soluble in boiling alcohol, crystallizing from this in needles which under the microscope appear as slender monoclinic prisms. It is sparingly soluble in warm chloroform, crystallizing on cooling in silky needles, and nearly insoluble in ether, benzene and petroleum ether.

It dissolves easily in cold alkali hydroxides, is precipitated from these solutions on addition of acids but redissolves in excess of these.

When boiled with acids (10 per cent. sulphuric acid) it is quantitatively converted into di- α -oxybutyrylurea.

α -Oxyisovalerylcyanamide, $(\text{CH}_3)_2\text{CH}.\text{CHOH}.\text{CO}.\text{NH}.\text{CN}$, was made in a similar way as the oxybutyryl compound, namely, by boiling 2.4 grams sodium in 100 cc. absolute alcohol with 9 grams thiourea and 14.6 grams ethyl α -oxyisovalerate for one hour. The alcohol was then distilled off as completely

as possible and acetic acid (10 per cent.) added in the usual way, whereupon the α -oxyisovalerylcyanamide separated out. It was washed with cold water and dissolved in boiling water, from which it crystallized in groups of very irregular flat needles apparently monoclinic. The yield was 11 grams, or about 77 per cent. of the theoretical. The substance began to soften at 216° and melted at 219° .

0.2269 gram substance gave 0.4182 gram CO_2 and 0.1434 gram H_2O .

0.1684 gram substance gave 31.0 cc. N at 25° and 738 mm.

	Calculated for $\text{C}_6\text{H}_{10}\text{O}_2\text{N}_2$.	Found.
C	50.67	50.27
H	7.09	7.04
N	19.72	19.92

α -Oxyisovalerylcyanamide is only slightly soluble in cold water, readily soluble in boiling water. It is quite readily soluble in cold alcohol and easily soluble in warm alcohol, from which it crystallizes in small needles appearing under the microscope as long slender monoclinic prisms. It is almost insoluble in ether, chloroform and benzene.

It dissolves very easily in cold caustic alkalies, is precipitated from these solutions on addition of acids, but redissolves in excess of these.

Like the other cyanamides of this class it is quantitatively converted into di- α -oxyisovalerylurea on boiling with 10 per cent. sulphuric acid.

LABORATORIES OF PARKE, DAVIS AND CO.,
June, 1909.

[Contributions from the Sheffield Laboratory of Yale University.]

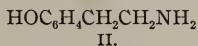
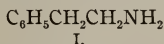
CLXX.—RESEARCHES ON AMINES: SYNTHESIS OF METHYLPHENYLETHYLAMINE.

[FIRST PAPER.]

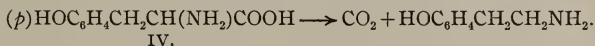
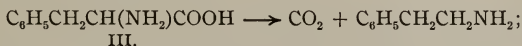
BY TREAT B. JOHNSON AND HERBERT H. GUEST.

The progress of physiological research in recent years has demonstrated the importance of a thorough chemical in-

vestigation of the bases phenylethylamine and *p*-oxyphenylethylamine. Results have been obtained which show that these bases, and several of their derivatives, occupy a prominent position among the aromatic compounds which are found among the decomposition products of proteins. Notwithstanding the fact that it has been known for a long time that they are formed in digestion and metabolism, yet our knowledge of them is extremely meagre. This paper may therefore be considered as a preliminary contribution to the study of substitution products of phenylethylamine (I) and *p*-oxyphenylethylamine (II):



These two bases have been obtained as cleavage products in protein metabolism and are formed from the amino acids phenylalanine (III) and tyrosine (IV), respectively, by the action of specific enzymes:



Gautier and Étard¹ observed that phenylethylamine is formed, with other bases, by the putrefaction of fish flesh (mackerel), but assigned to it the incorrect formula $\text{C}_8\text{H}_{13}\text{N}$. Nencki² and later Spiro³ obtained it among the decomposition products of gelatin after putrefaction with pancreas, and isolated it in the form of its platinum chloride double salt and its benzoyl derivative. It is interesting to note here that O. de Coninck⁴ obtained a base having the empirical composition $\text{C}_8\text{H}_{11}\text{N}$ by putrefaction of the flesh of cuttle fish, with the sepia bags removed. An amine having this same composition was also obtained by Emmerling⁵ by the action of bacteria (*streptococci*) on fibrin from swine blood.

¹ Compt. Rend., **94**, 1601.

² Nencki's Opera Omnia, **1**, 195; **2**, 171; J. prakt. Chem., **26**, 47; Monats. Chem., **10**, 506; Sitzun. Wien., **1889**, 10.

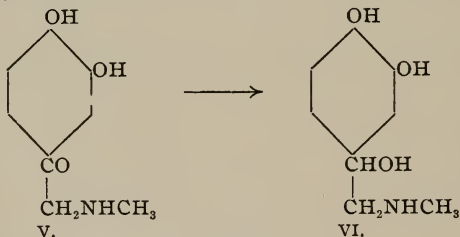
³ Beitr. chem. Physiol. (Hofmeister), **1**, 347.

⁴ Compt. Rend., **106**, 858, 1604.

⁵ Ber. d. chem. Ges., **30**, 1863.

Emerson¹ discovered *p*-oxyphenylethylamine among the products of autodigestion of beef pancreas and later Langstein² identified the base as one of the cleavage products in peptic digestion of ovalbumin. Van Slyke and Hart³ found the base among the proteolytic end-products formed during the ripening of Cheddar cheese and later Winterstein and K  ng⁴ observed that it is also a normal constituent of Emmentaler cheese. Barger and Walpole⁵ isolated the base from putrid meat and recently Barger⁶ has found that it is one of the active principles of ergot.

An important derivative of *p*-oxyphenylethylamine is adrenaline (suprarenine, epinephrine), the principle of the suprarenal glands which raises the blood pressure.⁷ This has been isolated,⁸ synthesized and shown to be identical with the amino alcohol⁹ (VI), obtained by reduction of methylaminoacetopyrocatechol¹⁰ (V):



¹ Beitr. chem. Physiol. (Hofmeister), **1**, 501.

² *Ibid.*, **1**, 507; **2**, 229.

³ THIS JOURNAL, **30**, 8.

⁴ Z. physiol. Chem., **59**, 138.

⁵ J. Physiol., **38**, 343.

⁶ J. Chem. Soc., **95**, 1123.

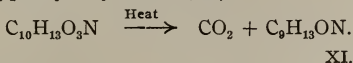
⁷ Oliver and Sch  fer: J. Physiol., **18**, 230. Szymonowicz and Cybulski: Centralb. Physiol., **9**, 172.

⁸ Takamine: Am. J. Pharm., **73**, 535. Aldrich: Am. J. Physiol., **5**, 457. V. Furth: Sitzun. Wien., **1903**, 112; Monats. Chem., **24**, 261. Abel: Ber. d. chem. Ges., **36**, 1839; **37**, 368.

⁹ Pauly: Ber. d. chem. Ges., **36**, 2944; **37**, 1388; **41**, 4151; **42**, 484. Abderhalden and Bergell: *Ibid.*, **37**, 2022. Jowett: J. Chem. Soc., **85**, 192 (1904); **87**, 967 (1905). Bertrand: Compt. Rend., **139**, 502. Friedmann: Beitr. chem. Physiol. (Hofmeister), **6**, 92; **8**, 95. Stolz: Ber. d. chem. Ges., **37**, 4149; D. R. P.: 152,814 and 157,300. Mayer: Centralb., **1904**, II, 1744. Dakin: *Ibid.*, **1905**, II, 57. B  ttcher: Ber. d. chem. Ges., **42**, 253.

¹⁰ Dzezgowski: Bull. Soc. Chim., [3] **12**, 911; Centralb., **1893**, II, 475.

Leger¹ separated from extracts of barley malt the alkaloid *hordenine*, $C_{10}H_{15}ON$, and its structure was established independently by him and by Gäbel,² who showed that it is *dimethyl-p-oxphenylethylamine* (XII). A base found in nature, which apparently is closely related to hordenine, is *surinamine* (*ratanhine*, *angeline*, *geoffroyine* or *andirine*), which was first discovered by Hütter in the bark of *Geoffroya surinamensis*, Murr,³ and was employed as an anthelmintic. This same base has also been found in other plants by Wittstein,⁴ Ruge,⁵ Peckolt,⁶ Winckler,⁷ Gintyl⁸ and Kreitmair.⁹ The recent work of Blau¹⁰ seems to indicate that it is a higher homologue of tyrosine. He has shown that it decomposes, on heating above its melting point, giving a base which is isomeric with methyl-*p*-oxyphenylethylamine (XI):



Gautier¹¹ isolated a base having this same empirical constitution, $C_9H_{13}ON$, and also *p*-oxyphenylethylamine from sea water in which cod fish livers had been allowed to putrefy. So far as the writer is aware, no nitrogen methyl derivative of phenylethylamine has yet been found in plants or identified among the cleavage products of proteins.

Phenylethylamine¹² (VII) and *p*-oxyphenylethylamine¹³ (X)

¹ Compt. Rend., **142**, 108; **143**, 234, 916; **144**, 208, 488; Bull. Soc. Chim., [3] **35**, 235, 868, 1157; [4] **1**, 148; J. Pharm. Chim., [6] **23**, 177; **25**, 5, 273.

² Arch. Pharm., **244**, 435.

³ Magazin Pharm., **7**, 287.

⁴ Jahres. d. Chem., **1854**, 656.

⁵ Arch. Pharm., [2] **111**, 1; Z. Chem. Pharm., **1862**, 447; Centralb., **1868**, 1158; Jahres. d. Chem., **1862**, 493.

⁶ Z. oesterr. Apoth.-Ver., **1868**, 518.

⁷ Jahrb. d. Pharm., **2**, 159.

⁸ Sitzun. Wien., **58**, 443; Centralb., **1869**, 394.

⁹ Ann. Chem. (Liebig), **176**, 64.

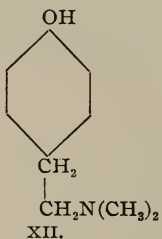
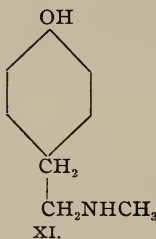
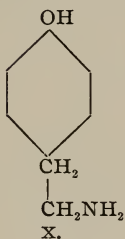
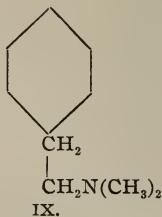
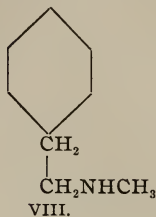
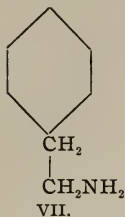
¹⁰ Z. physiol. Chem., **58**, 153.

¹¹ Bull. Soc. Chim., **35**, 1195 (1906); Centralb., **1907**, I, 546.

¹² Spica and Colombo: Gazz. Chim. Ital., **5**, 124. Bernthsen: Ann. Chem. (Liebig), **184**, 304. Spica: Jahres. d. Chem., **1879**, 440. Ladenburg: Ber. d. chem. Ges., **19**, 783. Bischler and Napieralski: Ber. d. chem. Ges., **26**, 1905. Erlenmeyer and Lipp: Ann. Chem. (Liebig), **219**, 202. Schulze and Barbieri: J. prakt. Chem., [2] **27**, 346; Ber. d. chem. Ges., **14**, 1788; **16**, 1713. Hoffmann: Ber. d. chem. Ges., **18**, 2740. Hoogewerff and Dorp: Rec. Trav. Chim., **5**, 254. Henze: Ber. d. chem. Ges., **31**, 3065.

¹³ Schmitt and Nasse: Ann. Chem. (Liebig), **133**, 214.

are the only ones of the six amines represented below (formulas VII to XII), which have been synthesized.¹



We describe, in this paper, the preparation and properties of the second member of this series, *viz.*, *methylphenylethylamine* (VIII).

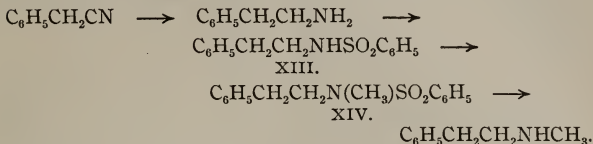
Phenylethylamine was prepared from benzyl cyanide by reduction with sodium and alcohol,² and converted into its benzenesulphone derivative (XIII) by treatment with benzenesulphone chloride in presence of alkali. The nitrogen methyl derivative, *benzenesulphonemethylphenylethylamine* (XIV), was then prepared according to the directions of Hinsberg³ by the action of methyl iodide on the sodium salt of the amide.

¹ Since the completion of the experimental part of this paper, Barger (*loc. cit.*) has published a paper describing the preparation of *p*-oxyphenylethylamine by the reduction of *p*-oxybenzyl cyanide, $\text{HOC}_6\text{H}_4\text{CH}_2\text{CN}$. Pschorr, Wolfes and Buckow: *Ber. d. chem. Ges.*, **33**, 171.

² Ladenburg: *Loc. cit.*

³ *Ann. Chem. (Liebig)*, **265**, 183.

A quantitative yield of methylphenylethylamine was obtained by hydrolysis of this amide with hydrochloric acid at 150°–160°. The various transformations in this synthesis are represented by the following formulas:



Methylphenylethylamine (VIII) is a strong base which has a characteristic amine odor and absorbs carbon dioxide from the air. It boils at practically the same temperature, under diminished pressure, as phenylethylamine (VII) and is volatile with water, alcohol, and ether vapors. It is precipitated from an aqueous solution of its hydrochloride by the alkaloid reagents phosphotungstic acid and mercuric chloride, and gives a heavy brick-red precipitate with potassium-bismuth iodide. The picrate, picrolonate and platinum chloride salts are

Table I.

$\text{C}_6\text{H}_5\text{CH}_2\text{CH}_2\text{NH}_2$ (phenylethyl- amine). Melting points.	Derivatives.	$\text{C}_6\text{H}_5\text{CH}_2\text{CH}_2\text{NHCH}_3$ (methylphenyl- ethylamine). Melting points.
217° ^{1,4}	Hydrochloride	152°–154°
255°–260°, with effer.	Platinum chloride salt	212°, with effervesc.
168° ³	Picrate	141°
	Picrolonate	217°–218°
112° ²	Urea = NCONH_2	141°
114° ³	Phenylurea = $\text{NCONHC}_6\text{H}_5$	104°–105°
209°–210°	α -Naphthylurea = $\text{NCONHC}_{10}\text{H}_7$	106°
106° ²	Phenylthiourea = $\text{NCSNHC}_6\text{H}_5$	113°–114°
68°–69°	Benzenesulphone = $\text{NSO}_2\text{C}_6\text{H}_5$	oil
65°–66°	<i>p</i> -Toluenesulphone = $\text{NSO}_2\text{C}_6\text{H}_4\text{CH}_3$	
181°	Acid oxalate	183°–184°

¹ Fileti and Piccini: Ber. d. chem. Ges., **12**, 1700. Haushofer: Jahres. d. Chem., **1883**, 703.

² Spica: Gazz. Chim. Ital., **9**, 568.

³ Bischler and Napieralski: Ber. d. chem. Ges., **26**, 1907. Michaelis and Linow: *Ibid.*, **26**, 2167.

⁴ Bertram and Walbaum: J. prakt. Chem., [2] **50**, 559.

difficultly soluble in water and have definite and sharp melting points. The melting points of a series of derivatives which are suitable for the identification of phenylethylamine and methylphenylethylamine are given in Table I. The physiological action of methylphenylethylamine is being investigated.

EXPERIMENTAL PART.

Phenylethylamine, $C_6H_5CH_2CH_2NH_2$.—We prepared this base according to Ladenburg's directions¹ by reduction of benzyl cyanide with sodium and ethyl alcohol. Of the various methods of preparation described in the literature, this appears to be the simplest and most practical.

Benzyl cyanide was dissolved in Kahlbaum's absolute alcohol (100 grams of the cyanide in 1200 cc. of alcohol) and the sodium (6 molecular proportions) slowly added to the hot alcohol solution. The mixture was then heated on the steam bath until all the sodium dissolved, cooled, and mixed with about one-fourth to one-third its volume of cold water. The excess of alcohol was then removed by distillation and the phenylethylamine separated from the alkaline fluid by steam distillation and converted into its hydrochloride. The crude salt which was obtained after evaporation was then decomposed with strong potassium hydroxide solution and the base extracted with ether, dried over stick potash, and purified by distillation under diminished pressure. Part of the benzyl cyanide underwent reduction by the sodium to toluene, with formation of ammonia and methylamine. Therefore, only about 65 per cent. of the crude salt obtained was pure phenylethylamine hydrochloride and the yield of amine was about 30–40 per cent. of the calculated. This yield was not increased by using more than 6 molecular proportions of sodium for the reduction. The yields obtained in six different preparations are given in Table II. The low yields in Experiments 1, 5 and 6 are explained by the fact that we used crude benzyl cyanide which was contaminated with a large amount of phenylacetamide.

¹ *Loc. cit.*

Table II.

	$\text{C}_6\text{H}_5\text{CH}_2\text{CN}$.	Alcohol.	Sodium.	Yield of crude hydrochloride.	Percentage of $\text{C}_6\text{H}_5\text{CH}_2\text{CH}_2\text{NH}_2$. HCl.	Yield of amine.	Per cent. of calculated.
	Grams.	cc.	Grams.	Grams.	Per cent.	Grams.	Per cent.
1	25.0	400.0	35.0	17.0	60.0	8.0	31.0
2	50.0	750.0	70.0	40.0	64.0	20.0	38.8
3	100.0	1200.0	120.0	70.0	82.2	45.0	43.7
4	100.0	1400.0	140.0	77.0	65.0	39.0	38.0
5	100.0	1200.0	120.0	65.0	62.0	31.5	30.5
6	100.0	1400.0	140.0			32.0	31.0

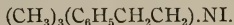
Action of Methyl Iodide on Phenylethylamine.—Methyl iodide reacts violently with this base. Two grams of the amine were dissolved in 25 cc. of ether and 2.2 grams (1 mol. = 2.26 grams) of methyl iodide, diluted with ether, added slowly to the solution of the base. There was an immediate reaction and in a few minutes the ether became turbid and an oil separated in drops which adhered to the sides of the flask. This finally solidified, on standing, in the form of plates. The mixture was heated to boiling for a few minutes to complete the reaction and the salt filtered off. It was extremely soluble in cold water and absolute alcohol but was precipitated from alcohol solutions by addition of ether. It crystallized in plates and was dried, for analysis, in a desiccator over potassium hydroxide and sulphuric acid. When heated in a capillary tube the salt begins to turn brown above 190° and decomposes at 235° – 236° . An iodine determination agreed with the calculated value for the *hydriodide of phenylethylamine*, $\text{C}_6\text{H}_5\text{CH}_2\text{CH}_2\text{NH}_2\cdot\text{HI}$.

0.2122 gram of salt gave 0.1968 gram of AgI.

	$\text{C}_6\text{H}_{12}\text{NI}$.	Calculated for $\text{C}_6\text{H}_{14}\text{NI}$.	Found.
I	51.00	48.2	50.4

The ether filtrate, above, was allowed to concentrate by slow evaporation and a crystalline salt separated. This was less soluble in alcohol than the hydriodide described above and crystallized from hot alcohol in colorless plates

which melted at 227° to a clear oil without effervescence. A mixture of this salt and phenylethylamine hydriodide melted at 170° – 190° . The properties of this compound and an iodine determination indicated that it was a quaternary salt, or *trimethylphenylethylammonium iodide*,



0.1481 gram of salt gave 0.1194 gram of AgI.

	Calculated for $\text{C}_{11}\text{H}_{18}\text{NI}.$	Found.
I	43.64	43.56

1-Phenylethyl-2- α -naphthylurea,

$\text{C}_6\text{H}_5\text{CH}_2\text{CH}_2\text{NHCONHC}_{10}\text{H}_7(\alpha)$.—Prepared by the action of α -naphthyl isocyanate on phenylethylamine. It is insoluble in water and crystallizes from hot 95 per cent. alcohol in needles felted together. It melts at 209° – 210° to an oil without effervescence. Analysis (Kjeldahl):

	Calculated for $\text{C}_{16}\text{H}_{18}\text{ON}_2.$	Found.
N	9.65	9.9

Benzenesulphonephenylethylamine,

$\text{C}_6\text{H}_5\text{CH}_2\text{CH}_2\text{NH}\text{SO}_2\text{C}_6\text{H}_5$.—Practically a quantitative yield of this amide was obtained by dissolving molecular proportions of benzenesulphonechloride (51.2 grams) and phenylethylamine (35 grams) in benzene and then shaking this solution with an aqueous solution of potassium hydroxide (1.5 mols.). After the reaction was complete the benzene layer was removed and the excess of benzene expelled by heating on the steam bath. We obtained the amide as an oil which soon solidified on cooling. It is very soluble in alcohol, benzene, chloroform, and acetone, and insoluble in water. It was purified by crystallization from a mixture of benzene and petroleum ether. It separates from a hot, saturated alcohol solution in six-sided, tabular crystals melting at 68° – 69° to a clear oil. Analysis (Kjeldahl):

	Calculated for $\text{C}_{14}\text{H}_{15}\text{O}_2\text{NS}.$	Found.
N	5.36	5.21

p-Toluenesulphonephenylethylamine,

$C_6H_5CH_2CH_2NH\text{SO}_2C_6H_4CH_3$.—This amide was prepared from *p*-toluenesulphonechloride and phenylethylamine in the same manner as the benzenesulphonephenylethylamine. It is very soluble in alcohol, acetone, chloroform, and benzene. It crystallizes from a mixture of benzene and petroleum ether in radiating needles, which melt at 65° – 66° to a clear oil. A mixture of the amide and the acid chloride (m. 69°) melted at 44° . Analysis (Kjeldahl):

	Calculated for $C_{15}H_{17}O_2NS$.	Found.
N	5.09	5.00

Benzenesulphonemethylphenylethylamine,

$C_6H_5CH_2CH_2(CH_3)N.SO_2C_6H_5$.—Sixty-five grams of benzenesulphonephenylethylamine were dissolved in 100 cc. of 95 per cent alcohol, and 11 grams of sodium hydroxide, dissolved in 15 cc. of water, added quickly to the alcohol solution. There was an immediate reaction and the sodium salt of the amide finally separated in colorless crystals. Forty-five grams of methyl iodide (1 mol. = 35.3 grams) were then added in small portions and the reaction allowed to take place at ordinary temperature. The salt reacted at once with the iodide, with evolution of heat, and it was necessary to heat only a few minutes, after the final addition of methyl iodide, in order to complete the reaction. The crude amide separated, on cooling, in the bottom of the flask as an insoluble oil which was dissolved in ether. More of the amide was obtained when the alcohol was diluted with water. After drying with calcium chloride and evaporating off the excess of ether the amide was obtained as a heavy oil, which did not crystallize after standing several days. We made no attempt to distil it under diminished pressure and the crude material was used in the following experiment. The yield of amide was practically quantitative.

Methylphenylethylamine, $C_6H_5CH_2CH_2NHCH_3$.—The crude amide from the preceding experiment was heated, under pressure, with 120 cc. of concentrated hydrochloric acid, at 150° – 160° for 2 hours. We obtained a clear solution which

was heated for several hours on the steam bath to remove the excess of hydrochloric acid, and then treated with an excess of strong aqueous potassium hydroxide solution. The base was extracted with ether, dried over potash, and then purified by distillation under diminished pressure. It boils at 112° .5– 115° at 36–40 mm. pressure. Analysis (Kjeldahl):

N	Calculated for $C_9H_{13}N$.	Calculated for $C_9H_{11}N$.	Found.	
	10.37	11.57	I.	II.
			10.24	10.30

The yield of pure distilled base was 27.0 grams. This did not, however, represent the total yield of base. We observed that this amine distils with ether vapors, and when hydrochloric acid gas was passed into the ether distillates the anhydrous hydrochloride of methylphenylethylamine separated in colorless plates melting at 152° – 154° to a viscous oil. When picric acid was added to an aqueous solution of this salt the characteristic picrate of methylphenylethylamine (see below) melting at 141° to an oil separated. About 2.5 grams of the base were recovered from the ether distillates.

Methylphenylethylamine is a strong base which absorbs carbon dioxide from the atmosphere. It has a distinct amine odor and shows a strong alkaline reaction with turmeric and litmus. It appears to be more soluble in water than phenylethylamine. It is precipitated from an aqueous solution by phosphotungstic acid and reacts with potassium-bismuth iodide, giving a brick-red precipitate. Addition of mercuric chloride to an aqueous solution of its hydrochloride gave a well crystallized mercury chloride double compound, which melted at 172° – 173° to an oil with no effervescence. This melting point was not raised by crystallization from water. The salt is not decomposed at its melting point and on cooling, it solidifies and then melts again at the same temperature. The gold chloride double salt is an oil.

Hydrochloride, $C_9H_9CH_2CH_2NHCH_3.HCl.2H_2O$.—This salt is extremely soluble in water and alcohol. It is very hygroscopic and the analytical determinations indicated that it contains two molecules of water of crystallization. It is

precipitated from alcohol, by addition of ether, in the form of plates which melt at 152° – 154° to a viscous oil with no effervescence. It was dried for analysis (Kjeldahl) in a desiccator over sulphuric acid:

	Calculated for $C_6H_{13}N.HCl.2H_2O$.	Found.
N	8.1	8.2

Picrate, $C_6H_5CH_2CH_2NHCH_3.C_6H_3O_7N_3$.—This salt was obtained when picric acid was added to an aqueous solution of the hydrochloride. It separated as an oil, which soon crystallized in prismatic crystals. They were badly etched, and melted at 141° to a clear oil with no effervescence. The salt does not contain water of crystallization. Analysis (Kjeldahl):

	Calculated for $C_6H_{13}N.C_6H_3O_7N_3$.	Found.
N	15.38	15.43

Picrolonate.—This salt is less soluble in water than the picrate. It crystallizes from water in two distinct forms according to the rate of cooling. When cooled quickly the salt separates in bunches of slender prisms or needles radiating from a common center. On the other hand, if the solution is allowed to cool slowly the salt deposits in large, tabular crystals. Both forms melt at 217° – 218° to a red oil with only slight effervescence.

Platinum Chloride Salt, $(C_6H_5CH_2CH_2NHCH_3.HCl)_2PtCl_4$.—Separates at once when hydrochloroplatinic acid is added to an aqueous solution of the hydrochloride. It crystallizes from hot water in characteristic, sharp-edged prisms, which melt at 212° with effervescence. It did not lose weight when heated at 100° – 110° for one hour. Analysis:

0.1456 gram of salt gave 0.0413 gram of Pt.

	Calculated for $(C_6H_{13}N.HCl)_2PtCl_4$.	Found.
Pt	28.67	28.35

Acid Oxalate, $C_6H_5CH_2CH_2NHCH_3.(COOH)_2$.—This salt was prepared by adding the base to a cold, saturated, aqueous solution of oxalic acid. It separated at once in glistening

plates, which melted at 183° – 184° to an oil with effervescence. It was dried at 60° – 70° for analysis (Kjeldahl):

	Calculated for $C_{20}H_{28}O_4N_2$.	Calculated for $C_{11}H_{15}O_4N$.	Found.
N	7.77	6.22	6.33

1,1-Methylphenylethylurea, $C_6H_5CH_2CH_2(CH_3)N.CONH_2$.—This was prepared by dissolving an excess of potassium cyanate in an aqueous solution of methylphenylethylamine hydrochloride and then evaporating the solution on the steam bath. The urea separated in colorless crystals and crystallized from hot water in plates melting at 141° to a clear oil with no effervescence. It is very soluble in boiling alcohol. Analysis (Kjeldahl):

	Calculated for $C_{10}H_{14}ON_2$.	Found.
N	15.73	15.55

1,1-Methylphenylethyl-2-phenylurea, $C_6H_5CH_2CH_2(CH_3)NCONHC_6H_5$.—This was prepared by the action of phenyl isocyanate on methylphenylethylamine. It is insoluble in water and very soluble in hot alcohol and benzene. It crystallizes from 95 per cent. alcohol in rectangular plates which melt at 104° – 105° to a clear oil with no effervescence. Analysis (Kjeldahl):

	Calculated for $C_{16}H_{18}ON_2$.	Found.
N	11.02	10.75

1,1-Methylphenylethyl-2- α -naphthylurea, $C_6H_5CH_2CH_2(CH_3)NCONHC_{10}H_7(\alpha)$.—From methylphenylethylamine and α -naphthyl isocyanate. It is very soluble in benzene and alcohol and difficultly soluble in water. It separates from hot 95 per cent. alcohol as an oil, which slowly crystallizes in rosettes of microscopic needles melting at 105° – 106° . It is precipitated from benzene by addition of petroleum ether. Analysis (Kjeldahl):

	Calculated for $C_{20}H_{20}ON_2$.	Found.
N	9.21	9.00

1,1-Methylphenylethyl-2-phenylthiourea, $C_6H_5CH_2CH_2(CH_3)NCSNHC_6H_5$.—Phenyl isothiocyanate reacts

with methylphenylethylamine, giving a quantitative yield of this thiourea. It is difficultly soluble in water and crystallizes from 95 per cent. alcohol in bundles of long prisms, which melt at 113° – 114° to an oil. Analysis (Kjeldahl):

	Calculated for $C_{16}H_{18}N_2S$.	Found.
N	10.37	10.17

NEW HAVEN, CONN.,
July, 1909.

[Contributions from the Sheffield Laboratory of Yale University.]

CLXXI.—RESEARCHES ON PYRIMIDINES:

DIMETHYL DERIVATIVES OF 2-AMINOPYRIMIDINE. PREPARATION OF 2-METHYLAMINO-5-METHYL- PYRIMIDINE.

[FORTY-SIXTH PAPER.]

BY TREAT B. JOHNSON AND KENNETH G. MACKENZIE.¹

This paper is a preliminary contribution to the study of aminomethylpyrimidines having the empirical formula $C_6H_9N_3$. Our interest in aminopyrimidines of this composition was incited by a paper entitled "Ueber die chemische Zusammensetzung der japanischen Soja-Sauce oder Schōyu,"² in which the authors have described two decomposition products of *Schōyu* to which they have assigned the empirical formulas $C_6H_9N_3$ and $C_4H_{12}N_2$. They state that the substance, $C_6H_9N_3$, is probably an isomer of aminodimethylpyrimidine, but is not identical with any one of three pyrimidines of this constitution which have been described in the literature,³ viz., 2,6-dimethyl-4-aminopyrimidine,⁴ 2-amino-4,5-dimethylpyrimidine,⁵ and 2-amino-4,6-dimethylpyrimidine.⁶

¹ A part of this paper was presented as a thesis by Mr. Kenneth Gerard Mackenzie to the Faculty of the Graduate School of Yale University for the Degree of Master of Science (June, 1909).

² Suzuki, Aso, and Mitarai: Bull. Coll. Agriculture (Tokio Univ.), **7**, 477 (1907).

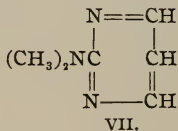
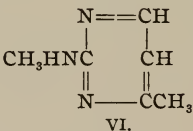
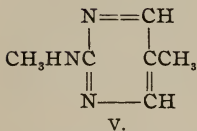
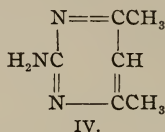
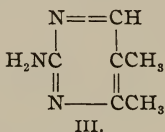
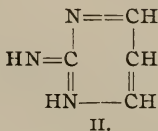
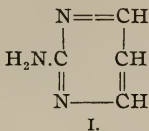
³ The Japanese investigators failed to recognize that a fourth isomer, 4,5-dimethyl-6-aminopyrimidine, has been prepared by Schlenker (Ber. d. chem. Ges., **34**, 2823). No salts of this pyrimidine have been described.—T. B. J.

⁴ Schwarze: J. prakt. Chem., **42**, 1 (1889). Schmidt: Ber. d. chem. Ges., **35**, 1577 (1902).

⁵ Schlenker: Ber. d. chem. Ges., **34**, 2819 (1901).

⁶ Angerstein: Ber. d. chem. Ges., **34**, 3962.

If we disregard the tautomeric form of 2-aminopyrimidine¹ (II), there are only five possible dimethyl derivatives of this pyrimidine (I), *viz.*, the two isomers described in the literature, 4,5-dimethyl²- and 4,6-dimethyl-2-aminopyrimidine³ (III and IV), 2-methylamino-5-methylpyrimidine (V), 2-methylamino-4-methylpyrimidine (VI), and 2-dimethylaminopyrimidine (VII).



We shall describe, in this paper, the preparation and properties of 2-methylamino-5-methylpyrimidine (V), and also some derivatives of the isomeric 2-methylamino-4-methylpyrimidine (VI). A description of a new method of preparing thymine has also been appended to this paper.

It has been shown in several papers from this laboratory⁴ that aryl substituted aminopyrimidines can be obtained, in practically quantitative yields, by heating 2-mercaptopyrimidines with aromatic bases. The action of aliphatic amines on mercaptopyrimidines has not been investigated. Since

¹ Büttner: *Ber. d. chem. Ges.*, **36**, 2229.

² Schlenker: *Loc. cit.*

³ Angerstein: *Loc. cit.*

⁴ Wheeler and Bristol: *THIS JOURNAL*, **33**, 438, 448. Johnson and Johns: *Ibid.*, **34**, 175. Johnson and Heyl: *Ibid.*, **38**, 238. Johnson and Storey: *Ibid.*, **40**, 131.

it was necessary for us to devise a practical method of preparing aliphylaminopyrimidines easily and in sufficient quantities for our work, we therefore investigated the action of methylamine on some 2-mercaptopyrimidines.

We now find that 2-methylmercapto-5-methyl-6-oxypyrimidine¹ (VIII), and 2-methylmercapto-4-methyl-6-oxypyrimidine² (IX), react with methylamine at 140°–150°, giving quantitative yields of 2-methylamino-5-methyl-6-oxypyrimidine (X) and 2-methylamino-4-methyl-6-oxypyrimidine (XI), respectively. The latter pyrimidine was identical with the 2-methylaminopyrimidine obtained by Jäger³ by alkylation of 2-amino-4-methyl-6-oxypyrimidine⁴ with methyl iodide. The same pyrimidine has also recently been prepared by Majima⁵ by condensing methylguanidine with ethyl acetoacetate. The yield by this method, however, corresponds to only about 50 per cent. of the theoretical, because part of the methylguanidine condenses, giving the isomeric 2-amino-3,4-dimethyl-6-oxypyrimidine.

These two 2-methylaminopyrimidines, (X) and (XI), reacted smoothly with phosphorus oxychloride, giving practically quantitative yields of 2-methylamino-5-methyl-6-chlorpyrimidine (XII) and 2-methylamino-4-methyl-6-chlorpyrimidine (XIII), respectively. Both of these pyrimidines underwent hydrolysis to the original 6-oxypyrimidines (X) and (XI), when an attempt was made to reduce them with hydriodic acid. On the other hand, they were converted into 2-methylamino-5-methylpyrimidine (V) and 2-methylamino-4-methylpyrimidine (VI), respectively, by reduction with zinc dust. We have not isolated the free 2-methylamino-4-methylpyrimidine,⁶ but have procured evidence of its formation, since we have obtained a picrate of the base and a characteristic zinc chloride double compound of definite

¹ Wheeler and Merriam: *THIS JOURNAL*, **29**, 487.

² List: *Ann. Chem. (Liebig)*, **236**, 12.

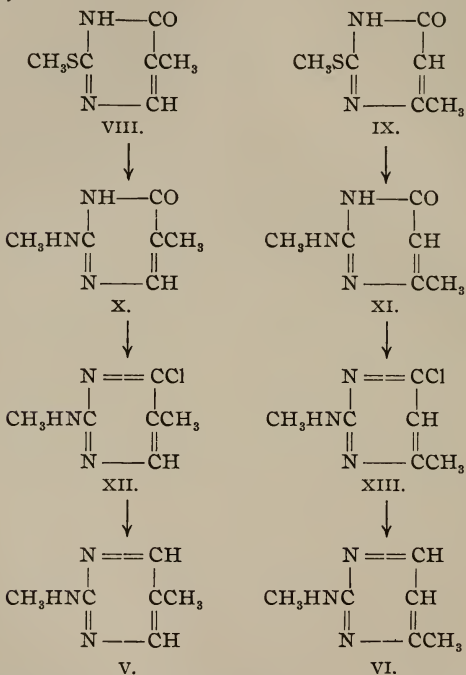
³ *Ann. Chem. (Liebig)*, **262**, 365.

⁴ Jäger: *Loc. cit.* Köhler: *Ber. d. chem. Ges.*, **19**, 220.

⁵ *Ber. d. chem. Ges.*, **41**, 176.

⁶ We were obliged to discontinue experiments on the reduction of 2-methylamino-4-methyl-6-chlorpyrimidine, because of the unexpected departure of one of us from the laboratory and on account of pressure of other work.—T. B. J.

constitution. The experimental evidence indicates that this methylaminopyrimidine is not identical with the base found in *Schöyu*.



2-Methylamino-5-methylpyrimidine (V) is not identical with the base $\text{C}_6\text{H}_9\text{N}_3$ which Suzuki and his coworkers isolated from *Schöyu*. They state that their base reacted with diazobenzenesulphonic acid, in the presence of alkali, giving an intense red color. Our pyrimidine and the diazo reagent gave at first no color, but on long standing a brilliant red color finally developed. A characteristic feature of their base was its tendency to form *acid salts*, *viz.*, the picrate

$C_6H_9N_3(C_6H_3O_7N_3)_2$, decomposing at 230° , and the hydrochloride $C_6H_9N_3 \cdot 2HCl$, melting at 232° – 233° . Our pyrimidines, on the other hand, are characterized by their tendency to form basic salts. The isomeric picrates, $(C_6H_9N_3)_2 \cdot C_6H_3O_7N_3$, of 2-methylamino-5-methylpyrimidine and 2-methylamino-4-methylpyrimidine both decomposed when heated above 150° . 2-Methylamino-5-methylpyrimidine formed a hydrous hydrochloride, $(C_6H_9N_3)_2 \cdot HCl \cdot H_2O$, melting at 162° – 163° . It is an interesting fact that 2-amino-5,6-dimethylpyrimidine¹ is the only dimethyl derivative of 2-aminopyrimidine, so far examined, that forms acid salts, *viz.*, the picrate and hydrochloride.

A New Method of Preparing Thymine.

In a previous paper from this laboratory one of the writers² showed that pseudomethylthiourea condenses smoothly, in aqueous solution, with the sodium salt of diethyl oxalpropionate, giving 2-methylmercapto-4-carboxyl-5-methyl-6-oxypyrimidine. When this acid, in small quantities, is heated above its melting point it undergoes a quantitative decomposition, with evolution of carbon dioxide, giving 2-methylmercapto-5-methyl-6-oxypyrimidine.³ A quantitative yield of thymine is then obtained by hydrolysis of this mercaptopyrimidine. The writer did not, at that time, lay stress on this method of synthesizing thymine because of the progress of other work in this laboratory on different methods of preparing this pyrimidine.

We have now investigated this method of preparation and find that the sodium salt of diethyl oxalpropionate condenses as smoothly, in aqueous solution, with pseudoethylthiourea as with pseudomethylthiourea, giving the corresponding 2-ethylmercapto-4-carboxyl-5-methyl-6-oxypyrimidine (XIV). This pyrimidine melts lower than the corresponding 2-methylmercapto compound⁴ and undergoes decomposition at its melting point, giving 2-ethylmercapto-5-methyl-6-oxypyrimi-

¹ *Loc. cit.*

² Johnson: *J. Biol. Chem.*, **3**, 299 (1907).

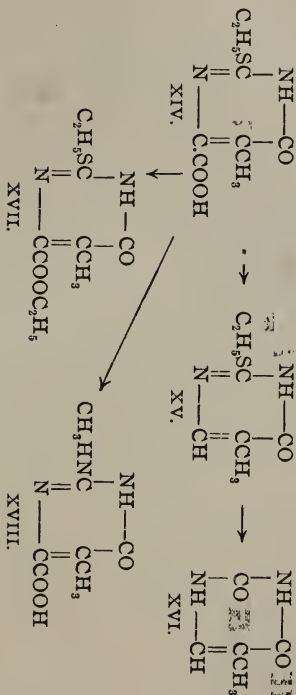
³ Wheeler and Merriam: *Loc. cit.*

⁴ Johnson: *Loc. cit.*

dine¹ (XV), which can be converted into thymine (XVI) by hydrolysis with hydrochloric acid. The success of this method of preparation was evidently dependent upon the fact whether large amounts of the mercapto acid (XIV) could be changed smoothly and quantitatively into 2-ethylmercapto-5-methyl-6-oxypyrimidine.² Working with small quantities, less than 15-16 grams of the acid, the decomposition into 2-ethylmercapto-5-methyl-6-oxypyrimidine was practically quantitative and the final yield of thymine corresponded to nearly 85-90 per cent. of the theoretical. On the other hand, when large amounts of 2-ethylmercapto-4-carboxyl-5-methyl-6-oxypyrimidine are decomposed under the same conditions the method is not practicable because it is then necessary to heat a long time, at a high temperature, in order to complete the reaction. Under such conditions secondary reactions set in with formation of products which contaminate the 2-ethylmercapto-5-methyl-6-oxypyrimidine and render its purification difficult. It is probable that these mercaptopyrimidines, when heated at high temperatures and in presence of impurities, slowly undergo dissociation into ethylene hydrocarbons and 2-thiopyrimidines. The ethyl ester of 2-ethylmercapto-4-carboxyl-5-methyl-6-oxypyrimidine (XVII) was obtained in one experiment as the chief product of the condensation. It was also formed quantitatively by the action of ethyl iodide on the silver salt of the mercapto acid (XIV). When the mercapto acid (XIV) was heated with methylamine, a quantitative yield of 2-methylamino-4-carboxyl-5-methyl-6-oxypyrimidine (XVIII) was obtained. These various transformations are represented by the following formulas:

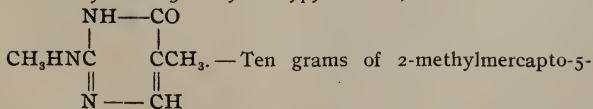
¹ Wheeler and Johnson: *THIS JOURNAL*, **31**, 595.

² *Loc. cit.*



EXPERIMENTAL PART.

2-Methylamino-5-methyl-6-oxypyrimidine,



methyl-6-oxypyrimidine¹ were heated with 18 grams of 33 per cent. methylamine solution (6 grams CH_3NH_2) at 140° – 150° for two hours. The clear solution was then transferred to a dis-

¹ *Loc. cit.*

tillation flask and the excess of methylamine expelled by passing a current of air through the boiling solution. On cooling, 8 grams of the aminopyrimidine separated, corresponding to 91 per cent. of the theoretical yield. In two other experiments, when 6 grams of the 2-methylmercaptopyrimidine were heated with 7.2 grams of 33 per cent. methylamine solution, under the same conditions, we obtained 5.0 and 5.3 grams of the crude pyrimidine.

This 2-methylaminopyrimidine is difficultly soluble in cold, but very soluble in hot water; soluble in boiling alcohol and benzene. It crystallizes from water in colorless, hairy crystals, which melt at 213° to a clear oil. The pyrimidine is characterized by its tendency to form supersaturated, aqueous solutions. It reacts with diazobenzenesulphonic acid in presence of sodium hydroxide, giving a strong, claret-red color. It contained one molecule of water of crystallization, which was determined by heating at 100° – 110° for one hour.

0.5821 gram substance lost 0.0584 gram H_2O .

	Calculated for $C_6H_9ON_3.H_2O$.	Found.
H_2O	11.4	10.03

Nitrogen determination in anhydrous substance (Kjeldahl):

	Calculated for $C_6H_9ON_3$.	Found.
N	30.22	30.23

Sulphate, $C_6H_9ON_3.H_2SO_4$.—Five-tenths gram of the pyrimidine base and 0.7 gram of sulphuric acid were dissolved in water and the solution allowed to concentrate in the air. The salt finally crystallized in large, transparent, tabular crystals, which melted at 202° to a brown oil. The salt is insoluble in alcohol but very soluble in water. It was dried at 100° for analysis (Kjeldahl):

	Calculated for $C_6H_9ON_3.H_2SO_4$.	I.	Found.	II.
N	17.72	17.51		17.83

Picrate, $(C_6H_9ON_3)_2.C_6H_3O_7N_3.H_2O$.—This salt was prepared by adding a solution of picric acid to an aqueous solution of the base. The picrate deposited in distorted prisms

which melted with decomposition at 240° . Analysis (Kjeldahl):

Calculated for $C_6H_9ON_3 \cdot C_6H_3O_7N_3$ = 22.82 per cent N.
 Calculated for $C_6H_9ON_3 \cdot (C_6H_3O_7N_3)_2$ = 21.10 per cent N.
 Calculated for $(C_6H_9ON_3)_2 \cdot C_6H_3O_7N_3 \cdot H_2O$ = 24.00 per cent N.

	I.	II.	III.	IV.
Nitrogen found:	23.89	24.12	24.20	24.25

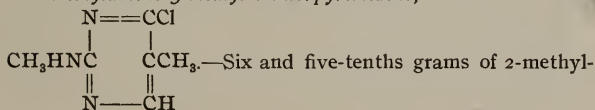
Platinum Chloride Salt, $(C_6H_9ON_3 \cdot HCl)_2 \cdot PtCl_4$, was prepared by addition of hydrochloroplatinic acid to an aqueous solution of the pyrimidine base. It did not contain water of crystallization. Platinum determinations:

I. 0.0889 gram of salt gave 0.0248 gram of Pt.

II. 0.0989 gram of salt gave 0.0277 gram of Pt.

	Calculated for $(C_6H_9ON_3 \cdot HCl)_2 \cdot PtCl_4$.	I.	Found.	II.
Pt	28.3	27.90		28.06

2-Methylamino-5-methyl-6-chlorpyrimidine,



amino-5-methyl-6-oxypyrimidine were dissolved, by warming, in 30 cc. of phosphorus oxychloride and the solution boiled for 30 minutes. The excess of phosphorus oxychloride was then removed by heating at 100° under diminished pressure, when a viscous liquid was obtained. This was dissolved in cold water and the solution made alkaline with sodium hydroxide, when the chlorpyrimidine separated. After drying in a vacuum over concentrated sulphuric acid it weighed 6.9 grams, corresponding to 95 per cent. of the theoretical. In a second experiment, when we used 10.6 grams of the 2-methylmercaptopyrimidine and 53 cc. of phosphorus oxychloride we obtained a yield of 11.5 grams of the chlorpyrimidine.

The pyrimidine is insoluble in water but soluble in alcohol and benzene. It sublimes at 100° and melts at 131° to a

clear oil with no effervescence. It crystallizes from 95 per cent. alcohol in prismatic crystals. Analysis (Kjeldahl):

	Calculated for $C_6H_8N_3Cl$.	Found.
N	26.67	26.83

2-Methylamino-5-methylpyrimidine,

$$\begin{array}{c}
 \text{N}=\text{CH} \\
 | \qquad | \\
 \text{CH}_3\text{HNC} \quad \text{CCH}_3\text{---} \\
 || \qquad || \\
 \text{N} \text{---} \text{CH}
 \end{array}$$

Five grams of 2-methylamino-5-methyl-6-chlorpyrimidine and 15 grams of zinc dust were suspended in 200 cc. of water and the mixture digested for 8 hours. The excess of zinc was then removed by filtration and the filtrate concentrated on the steam bath. We obtained a thick syrup which was dissolved in 25 cc. of water and an excess of a saturated, aqueous solution of potassium hydroxide added. A light colored precipitate was formed which was filtered by suction, and dried in a desiccator over sulphuric acid.

An attempt to purify this substance by sublimation was unsuccessful. The crude, dry material was finally extracted several times with boiling ether. When the excess of ether was evaporated, about 2 grams of a colorless, crystalline substance which melted at $97^\circ\text{--}100^\circ$ to a clear oil was obtained. In order to purify it for analysis it was dissolved in dry ligroin and the solution allowed to concentrate by slow evaporation. The pyrimidine separated under these conditions in beautiful, transparent prisms, which melted sharply at 102° to a clear oil. The pyrimidine is extremely soluble in cold water, ether, and benzene. It showed no alkaline reaction when tested with turmeric and was precipitated from an aqueous solution by mercuric chloride. It gave at first no color when tested with diazobenzenesulphonic acid, but on allowing the mixture to stand a strong red color finally developed. The pyrimidine sublimes when heated above 100° . Analysis:

	Calculated for $C_6H_9N_3$.	Found.
N	34.14	34.20

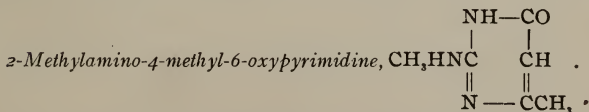
An attempt was made to reduce the 6-chlorpyrimidine with hydriodic acid, but it underwent hydrolysis, giving 2-methylamino-5-methyl-6-oxypyrimidine.

Picrate, $(C_6H_9N_3)_2 \cdot C_6H_3O_7N_3$.—This salt separated immediately when an aqueous solution of picric acid was added to a solution of the pyrimidine base. It had no definite melting point, but began to shrivel at about 100° and decomposed when heated above 150° . Analysis:

	Calculated for $(C_6H_9N_3)_2 \cdot C_6H_3O_7N_3$.	Found.
N	26.53	26.36

Hydrochloride, $(C_6H_9N_3)_2 \cdot HCl \cdot H_2O$.—This salt was prepared by dissolving the base in warm hydrochloric acid and concentrating the solution on the steam bath. It was extremely soluble in water, but crystallized from methyl alcohol in well-developed prismatic crystals. The salt melts at 162° – 163° to a clear oil and does not effervesce below 250° . Analysis:

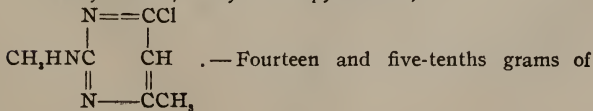
	Calculated for			Found.	
	$C_6H_9N_3 \cdot HCl$.	$C_6H_9N_3 \cdot 2HCl$.	$(C_6H_9N_3)_2 \cdot HCl \cdot H_2O$.	I.	II.
N	26.33	21.64	27.95	27.7	27.88



—We prepared this pyrimidine¹ by heating 2-methylmercapto-4-methyl-6-oxypyrimidine¹ with an excess of methylamine at 140° – 150° . The yield was quantitative and the pyrimidine melted at 201° – 202° after one recrystallization from hot water. Analysis (Kjeldahl):

	Calculated for $C_6H_9ON_3$.	Found.
N	30.22	30.00

2-Methylamino-4-methyl-6-chlorpyrimidine,



¹ *Loc. cit.*

2-methylamino-4-methyl-6-oxypyrimidine and 72 cc. of phosphorus oxychloride were heated in an oil bath at 120° – 130° for 30 minutes, when the evolution of hydrochloric acid gas had practically ceased. We obtained a clear solution which was then heated at 100° under diminished pressure to remove the excess of phosphorus oxychloride. A brown oil remained, which was dissolved in cold water, and the solution made alkaline with sodium hydroxide. The pyrimidine separated in colorless crystals and was dried in a desiccator over sulphuric acid. It is very insoluble in water but easily soluble in alcohol. It separates from an alcohol solution in long needles which melt at 135° to a yellow oil without effervescence. It slowly sublimes when heated above 100° . Analysis (Kjeldahl):

	Calculated for $C_6H_8N_3Cl$.	Found.
N	26.67	26.70

Reduction of 2-Methylamino-4-methyl-6-chlorpyrimidine with Zinc.—This chlorpyrimidine is very slowly reduced by digestion with zinc dust because of the insolubility of the pyrimidine in water. Unaltered chlorpyrimidine was recovered after 12 hours' digestion of 12 grams of the pyrimidine and 50 grams of zinc dust in 1000 cc. of water. One hundred cc. of alcohol were then added and the mixture boiled again for 10 hours, cooled and filtered. By extraction of the zinc residue with alcohol, we recovered 6 grams of unaltered 6-chlorpyrimidine. The aqueous filtrate was concentrated to a volume of 15–20 cc. and allowed to stand at ordinary temperature, when well-developed, red crystals separated. They melted sharply at 170° – 172° to an oil without effervescence and contained zinc and chlorine. The substance was extremely soluble in water and did not lose weight when heated at 100° – 110° . A nitrogen determination (Kjeldahl) agreed with the calculated value for a double compound containing 3 molecules of 2-methylamino-4-methylpyrimidine and one molecule of zinc chloride, $(C_6H_9N_3)_2 \cdot ZnCl_2$:

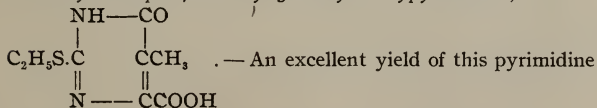
	Calculated for $(C_6H_9N_3)_2ZnCl_2$.	Found.
N	22.97	22.80

The filtrate obtained after separation of the zinc chloride compound was concentrated on the steam bath to a viscous liquid and then triturated with about 25 cc. of a strong, aqueous solution of potassium hydroxide. An amorphous substance was precipitated, which was separated by suction filtration, washed with a few drops of cold water, and dried in a desiccator over sulphuric acid. This substance was then extracted in a Soxhlet apparatus with ether for three days. When the ether was evaporated we obtained an oil which dissolved at once in water, alcohol and benzene. In order to establish the presence of 2-methylamino-4-methylpyrimidine, the oil was dissolved in water and a solution of picric acid added to the aqueous solution. A picrate separated at once in the form of irregular prisms which melted at 150° – 155° to an oil with no appreciable effervescence. This salt did not give a test for chlorine. Analysis (Kjeldahl):

	Calculated for		Found.
	$(C_6H_9N_3)_2 \cdot C_6H_3O_7N_3$	$C_6H_9N_3 \cdot C_6H_3O_7N_3$	
N	26.5	23.8	25.98

2-Methylamino-4-methyl-6-chlorpyrimidine was converted into 2-methylamino-4-methyl-6-oxypyrimidine when heated with hydriodic acid.

2-Ethylmercapto-4-carboxyl-5-methyl-6-oxypyrimidine,



is obtained by condensation of pseudoethylthiourea with the sodium salt of diethyl methyloxalacetate in aqueous solution. In our preliminary experiments this sodium salt was prepared by condensation of diethyloxalate with ethyl propionate in presence of sodium ethylate.¹ We found, however, that the use of dry sodium ethylate is unnecessary and that as good a yield of the salt can be obtained by condensation of the esters in anhydrous ether in presence of metallic sodium. This fact is shown by comparison of the yields of pyrimidine given in the table. Our method of preparing the pyrimidine

¹ Arnold: Ann. Chem. (Liebig), 246, 329.

was as follows: A mixture of 50 grams of ethyl propionate and 71 grams of diethyl oxalate was added slowly to dry ether, in which was suspended 11.5 grams of metallic sodium. After the esters had been added the mixture was allowed to stand about 2 days to insure a complete reaction. Cold water (about 500–600 cc.) was then cautiously added to dissolve the sodium salt, and the ether layer separated. To this aqueous solution was then added a concentrated, aqueous solution of 52 grams of pseudoethylthiourea hydrobromide and finally two molecular proportions of potassium hydroxide (32 grams). After allowing to stand for 2 days at 40°–50° the solution was concentrated to about one-half its original volume, cooled, and acidified with an excess of strong hydrochloric acid. The pyrimidine usually separated in the form of a light pink or nearly colorless, granular powder melting at 210°–215° with evolution of carbon dioxide. The yield of mercaptopyrimidine is decreased by using, for the condensation, more than two molecular proportions of potassium hydroxide because the pyrimidine is slowly converted into thymine-4-carboxylic acid,¹ with evolution of ethyl mercaptan, when warmed with strong alkaline solutions (Experiment 5 in table).

The proportion of pseudoethylthiourea hydrobromide to be used for a condensation was calculated upon the basis that the yield of sodium salt of diethyl oxalpropionate is only about 50 per cent. of the theoretical (Arnold² says 45 per cent.). Under these conditions, fifty grams of ethyl propionate require for condensation 45 grams of the pseudothiourea salt, which we increased to 52–54 grams or about 0.6 molecular proportion. The yield of pyrimidine was not increased by using more than this proportion (see Experiment 2 in table).

¹ Johnson: J. Biol. Chem., 3, 299.

² *Loc. cit.*

Table I.

	$\text{CH}_3\text{CH}_2\text{COOC}_2\text{H}_5$.	$(\text{COOC}_2\text{H}_5)_2$.	Na used.	$\text{C}_2\text{H}_5\text{SC}(\text{NH})_2\text{NH}_2$, HBr.	KOH used.	Yield of 2-mercapto-4-carboxyl-5-methyl-6-oxypyrimidine.
	Grams.	Grams.	Grams.	Grams.	Grams.	Grams.
1	50.0	71.0	11.5	52.0	16.0	36.0
2	50.0	71.0	11.5	72.0	22.0	36.5
3	50.0	71.0	11.5	54.0	32.0	34.0
4	50.0	71.0	11.5 in form NaOC_2H_5	54.0	32.0	37.0
5	100.0	144.0	22.5	100.0	108.0 (2.5 mols.)	60.0 and 15.0 of thymine-4-carboxylic acid ¹
6	50.0	71.0	11.5 in form NaOC_2H_5	45.0	30.0	22.0

2-Ethylmercapto-4-carboxyl-5-methyl-6-oxypyrimidine is soluble in boiling water but separates on cooling in clusters of slender needles and prismatic crystals. It is more soluble in alcohol than in water. It decomposes, after crystallization from water, from 215° – 218° with effervescence, giving 2-ethylmercapto-5-methyl-6-oxypyrimidine² (see below). If the acid is dissolved in dilute sodium hydroxide solution and reprecipitated by addition of hydrochloric acid it separates in colorless crystals melting sharply at 220° . The acid is not precipitated from aqueous solutions of its sodium salt by addition of acetic acid.

Analysis (Kjeldahl):

	Calculated for $\text{C}_8\text{H}_{10}\text{O}_3\text{N}_2\text{S}$.	I.	Found.	II.
N	13.08	13.3		13.2

Stability of the Sodium Salt of Diethyl Oxalpropionate, $\text{C}_2\text{H}_5\text{OOC.C}(\text{ONa})\text{:C}(\text{CH}_3)\text{COOC}_2\text{H}_5$.—Seventy-one grams of diethyl oxalate were condensed with 50 grams of ethyl propionate, in presence of sodium ethylate,³ on June 10, 1908. This salt was then allowed to stand exposed to the air, in an

¹ Johnson: *Loc. cit.*

² *Loc. cit.*

³ Arnold: *Loc. cit.*

open flask, until October 15, 1908. It was then condensed with pseudoethylthiourea in the usual manner, when we obtained 22 grams of pyrimidine melting at 209° – 214° (Experiment 6 in table).

Ethyl Ester of 2-Ethylmercapto-4-carboxyl-5-methyl-6-oxypyrimidine,

$$\begin{array}{c} \text{NH}-\text{CO} \\ | \quad | \\ \text{C}_2\text{H}_5\text{SC} \quad \text{CCH}_3 \\ || \quad || \\ \text{N}-\text{CCOOC}_2\text{H}_5 \end{array}$$

—The sodium salt of diethyl

oxalpropionate was prepared in the usual manner by condensing 71 grams of diethyl oxalate with 50 grams of ethyl propionate in presence of metallic sodium. This salt was then dissolved in 400–500 cc. of water and mixed with an aqueous solution containing 0.6 molecular proportion of pseudoethylthiourea. The mixture was then allowed to stand, at ordinary temperature, for several days, when 17.0 grams of the ethyl ester had separated. After concentrating the aqueous filtrate and then acidifying with hydrochloric acid, we obtained the corresponding acid. This ester is difficultly soluble in water but very soluble in boiling alcohol. It crystallizes from 95 per cent. alcohol in prisms which melt at 172° – 173° to a clear oil. It dissolves in sodium hydroxide solution without decomposition but on warming it easily undergoes saponification. The ester is also formed quantitatively by the action of ethyl iodide on the silver salt of 2-ethylmercapto-4-carboxyl-5-methyl-6-oxypyrimidine. Analysis (Kjeldahl):

	Calculated for $\text{C}_{10}\text{H}_{14}\text{O}_3\text{N}_2\text{S}$.	Found.
N	11.56	11.8

Behavior of 2-Ethylmercapto-4-carboxyl-5-methyl-6-oxypyrimidine on Heating.—A few grams of this mercaptopyrimidine (3–4 grams) were heated in an oil bath at 220° – 230° until effervescence ceased. A dark oil was obtained which solidified on cooling. This substance was purified by crystallization from hot water and separated in prisms melting at 159° . It was identified as 2-ethylmercapto-5-methyl-6-oxypyrimidine.¹ Analysis (Kjeldahl):

¹ Wheeler and Johnson: *Loc. cit.*

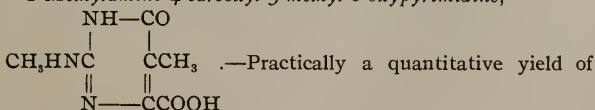
	Calculated for $C_7H_{10}ON_2S$.	Found.
N	16.47	16.6

Conversion of 2-Ethylmercapto-4-carboxyl-5-methyl-6-oxypyrimidine into Thymine.—Sixteen grams of this mercaptopyrimidine, melting at 218° – 220° , were heated in an oil bath at 220° – 230° until the evolution of carbon dioxide ceased (about 1.5 hours). We obtained 13.0 grams of crude 2-ethylmercapto-5-methyl-6-oxypyrimidine (theoretical yield is 12.7 grams), which was then digested for several hours with concentrated hydrochloric acid and converted into thymine. The acid solution was evaporated to dryness and the crude thymine decolorized in hot, aqueous solution with animal charcoal and then crystallized from water. It separated in colorless crystals, decomposing at about 325° – 335° . The yield was 8.0 grams, or about 85 per cent. of the theoretical. Since 36–37 grams of 2-ethylmercapto-4-carboxyl-5-methyl-6-oxypyrimidine can be obtained from 50 grams of ethyl propionate (see table) this amount of thymine (8 grams) therefore corresponds to 21.6 grams of the ester.

A quantitative yield of thymine from 21.6 grams of ethyl propionate would be 26.5 grams. Analysis (Kjeldahl):

	Calculated for $C_6H_8O_2N_2$.	Found.
N	22.22	22.00

2-Methylamino-4-carboxyl-5-methyl-6-oxypyrimidine,



this pyrimidine was obtained when 7 grams of 2-ethylmercapto-4-carboxyl-5-methyl-6-oxypyrimidine and 9 grams of a 33 per cent. solution of methylamine were heated at 140° – 150° for 4 hours. It was precipitated from cold, aqueous solutions of its sodium, ammonium and methylamine salts by addition of acetic acid. It was very insoluble in cold water and crystallized from hot water in long, hairy crystals which melted

at 270° – 280° , according to the rate of heating, with effervescence. Analysis (Kjeldahl):

	Calculated for $C_7H_9O_3N_3$.	Found.
N	22.9	22.4

Methylamine Salt, $C_7H_9O_3N_3 \cdot CH_3NH_2$.—This salt crystallized from hot water in granular crystals, which decomposed with violent effervescence at 274° . Two of the crystals that were used for analysis weighed 0.0393 and 0.03170 gram, respectively. Analysis (Kjeldahl):

	Calculated for $C_7H_9O_3N_3 \cdot CH_3NH_2$.	Found.
N	26.1	25.91

Hydrochloride, $C_7H_9O_3N_3 \cdot HCl$.—This salt was prepared by dissolving the pyrimidine base in hot, dilute hydrochloric acid and allowing the solution to cool. The salt separated in prismatic crystals, which decomposed at 276° – 283° with effervescence. Analysis (Kjeldahl):

	Calculated for $C_7H_9O_3N_3 \cdot HCl$.	Found.
N	19.14	19.32

NEW HAVEN, CONN.,
June 1, 1909.

REVIEWS.

JAHRBUCH DER CHEMIE. BERICHT ÜBER DIE WICHTIGSTEN FORTSCHRITTE DER REINEN UND ANGEWANDTEN CHEMIE. Unter Mitwirkung von H. BECKURTS, Braunschweig, C. A. BISCHOFF, Riga, M. DELBRÜCK, Berlin, J. M. EDER, Wien, P. FRIEDLÄNDER, Wien, C. HAEUSSERMANN, Ludwigsburg, A. HERZFELD, Berlin, K. A. HOFMANN, München, G. KEPPELER, Hannover, J. LEWKOWITSCH, London, A. MORGEN, Hohenheim, B. NEUMANN, Darmstadt, M. NIERENSTEIN, Liverpool, O. SACKUR, Breslau, K. SPIRO, Strassburg i. E., herausgegeben von RICHARD MEYER, Braunschweig. XVII. Jahrgang, 1907. Braunschweig: Friedrich Vieweg und Sohn. 1908. Price, M. 16.

The editor of this excellent and helpful publication calls attention to the fact that the chapter on "Physical Chemistry" has been prepared by Dr. O. Sackur, that the report on "Metallurgy" has been written by Professor B. Neumann, of Darmstadt; and that the chapter on the "Inorganic Chemical Industries," hitherto prepared by Dr. F. Quincke, has now been written by Dr. G. Keppler. He further states that technical chemical processes in which the electric current is the source of energy are thoroughly dealt with in the sections on "Metallurgy" and "Inorganic Chemical Industries."

The eighteen chapters of the book have the titles given below: I., Physical Chemistry; II., Inorganic Chemistry; III., Organic Chemistry; IV., Physiological Chemistry; V., Pharmaceutical Chemistry; VI., Chemistry of Foods; VII., Agricultural Chemistry; VIII., Fuels and Explosives; IX., Metallurgy; X., Inorganic Chemical Industries; XI., Technology of the Carbohydrates; XII., Fermentation Industries; XIII., Technology of Fats and Petroleums; XIV., Coal Tar and Dyestuffs, I.; XV., Coal Tar and Dyestuffs, II.; XVI., Chemical Technology of the Spinning Industries; XVII., Tanning; XVIII., Photography.

So far as the writer of this notice has been able to examine the volume, it appears to be of the same high merit as the earlier volumes, and it will be welcomed by the many who have used them.

I. R.

KURZES LEHRBUCH DER ORGANISCHEN CHEMIE. Von PROF. DR. A. BERNTHSEN, Grossherzogl. Bad. Hofrat, Dircktor der Badischen Anilin- und Soda-Fabrik, Ludwigshafen am Rhein, Früher Professor an der Universität zu Heidelberg. Zehnte Auflage. Bearbeitet in Gemeinschaft mit DR. ERNST MOHR, A. O. Professor an der Universität Heidelberg. Braunschweig: Friedr. Vieweg und Sohn. pp. 640. Price, M. 12.

In his preface the author says: "Although the tenth edition differs in appearance but slightly from the preceding, nevertheless the numerous advances in organic chemistry have been thoroughly taken into account, while an increase in the length of the book has been avoided by means of abbreviations in other parts. Bernthsen's "Organic Chemistry" is so favorably known that it is not necessary to tell chemists about it. There is no better book for the student who has already had an introduction to the subject. A careful study of each chapter will give him a very fair idea of the extent to which the subject has been developed, of the methods that have been used, and of the speculations that have resulted from a study of the facts. The chief objection to the book is its compactness. It is very strong meat and must be partaken of in small quantity at a time or indigestion will result. Take, for example, the sections entitled *Konstitution des Benzols*; *Benzoltheorie* and *Spezielle Benzolformeln*. There is certainly not a superfluous word in these sections. The question is, Are there enough words to make the treatment clear? Probably not. But there are references to the most important articles and books bearing on the subject, and the earnest student who wants to know will be able to work out the problem by studying the book and the literature referred to. The same general remarks may be made in regard to all the other sections of the book, and it thus appears that Bernthsen's

"Organic Chemistry" serves a double purpose. It is a condensed text-book and a sensible, eclectic guide to the literature, and, as such, can be highly recommended to all students of chemistry. I. R.

NEUERE THEORETISCHE ANSCHAUUNGEN AUF DEM GEBIETE DER ORGANISCHEN CHEMIE. Von Dr. FERDINAND HENRICH, A. O. Professor an der Universität Erlangen. Braunschweig: Friedr. Vieweg und Sohn. 1908. pp. 194. Price, M. 7.

This is a very interesting and valuable book that should be in the hands of every advanced student of chemistry. The subjects in the sixteen chapters are:

I. Lavoisier's dualistic views; II. The later theory of types and the first attack by Kekulé; III. van't Hoff's hypothesis regarding the form of the carbon atom; IV. Thiele's hypothesis of the partial valences; V. Attacks upon Thiele's theory; VI. Researches on the so-called negative nature of atomic groups; VII. Tautomerism and desmotropism; VIII. Pseudo acids, pseudo bases and ionization isomerism; IX. Color and chemical constitution; X. Fluorescence and chemical constitution; XI. Molecular rearrangements; XII. Basic properties of oxygen; XIII. J. U. Nef's theoretical views; XIV. A. Michael's theoretical system; XV. A. Werner's theory; XVI. Later electrochemical views.

Most of these chapters are summaries of the articles that have appeared in the journals. The summaries are clear and show that the author has read the articles with care. For the earnest student of chemistry, whether he is a university student in the narrower sense or a student in the broader and higher sense, the book will be of great value.

It is of especial interest that a chapter is devoted to the views of Michael and another to the views of Nef. In regard to the former the author says: "Without doubt, Michael's theory grasps the problems of organic chemistry in a broad way. By its aid it is possible to follow organic reactions much more in detail than formerly. Undoubtedly the further studies of Michael and his students will extend the theory especially on the quantitative side, and will in many ways simplify its use. Chemists may expect still further advances as a result of the further development of these views." It is to be hoped that the comparatively simple presentation of Michael's views will lead to a more thorough study of his original articles.

Speaking of Nef's views, the author says: "To-day Nef's proofs of the existence of compounds with bivalent carbon are pretty generally accepted. The same cannot be said of his other theoretical speculations, especially of the methylene

chemistry. Nevertheless, they are worthy of the highest consideration. They are frequently applied to reactions, especially to rearrangements, and give in such cases perhaps the most plausible explanation."

The book is cordially recommended.

I. R.

ANLEITUNG FÜR DAS ORGANISCH-PRÄPARATIVE PRAKTIKUM. Von DR. FRANZ WILHELM HENLE, früher Privatdozent an der Universität Strassburg. Mit einer Vorrede von Dr. J. THIELE, Professor an der Universität Strassburg. Mit zahlreichen Skizzen. Leipzig: Akademische Verlagsgesellschaft M. b. H. 1909. Preis, brosch., M. 4.60; gebunden, M. 5.20.

This book on organic preparations has a number of excellent features not always found in such treatises. The chief one is the fine list of references to the important articles on each subject treated. One page is given to a list of the necessary first outlay of apparatus, another to precautions against various accidents, and another to the first aid to those injured by burns, cuts, or harmful chemicals or gases.

The list of preparations is about the usual one, though not so full as that in Gattermann's book. The author might have omitted some of the list of *fifteen* compounds in which a halogen is introduced, and inserted others of greater importance in their place. The various methods of separating and purifying compounds (distillation, crystallization, etc.), are described as they are needed in making the first few preparations. This method probably impresses the student more forcefully than does the consideration of these manipulations in an introduction. A large number of test tube reactions of the various substances are given, but the actual equations representing the chief reactions are unfortunately omitted. The student is much more likely to master these characteristic reactions if he can read them in the book on organic preparations while he is dealing with the substances than he is if he is forced to go to a text-book on organic chemistry.

The paper, printing, cuts of apparatus, and graphical formulas are unusually fine. Altogether this volume should meet with a very hearty reception.

S. F. ACREE.

QUANTITATIVE EXPERIMENTS IN GENERAL CHEMISTRY. By JOHN TAPPAN STODDARD, Professor of Chemistry in Smith College. New York: Longmans, Green & Co. 1908. pp. vii + 115. Price, \$1.

This is a small manual for college use containing rough quantitative experiments illustrating the gas laws, densities of gases, specific heats, air, water, analysis of some simple gaseous compounds and of many metallic oxides, sulphides and salts. The book is not written as an elementary quantitative manual for chemists, but rather as a book for students not intending further study of chemistry to impress upon

their minds the quantitative significance of chemical law. The experiments are well selected and simple. E. R.

GESÄTTIGTE SALZLÖSUNGEN VON STANDPUNKT DER PHASENLEHRE. Von DR. PHIL. ERNST JÄNECKE, Privatdozent an der Königl. Technischen Hochschule in Hannover. Mit 83 Tabellen, 153 Abbildungen im Text. Halle a. S.: Verlag von Wilhelm Knapp. 1908. pp. 187. Price, M. 9.

This book, which the author dedicates to his teacher, van't Hoff, is based upon a course of lectures delivered in 1906 at the Technical High School in Hannover.

The work of Roozeboom, Meyerhoffer and especially van't Hoff, on the conditions of equilibria in solutions of salts is very well known in general. This work is brought together in a systematic form in this monograph and treated in terms of the phase rule. This is a welcome addition to physical chemical literature. The publications of these various authors were so widely scattered through the journals as to render them difficultly accessible to many who would like to follow these investigations in some detail.

Further, the individual papers dealing with the special topics were often difficult reading for those who had not followed closely the entire literature bearing upon the problems under investigation.

A well-arranged account of the work that has been done, and is in progress in this interesting field, is now at hand.

H. C. J.

MEAT AND FOOD INSPECTION. By WM. ROBERTSON, M.D., D.P.H.F.P.S. With Regulations Governing Meat Inspection in the United States. By MAXIMILIAN HERZOG, M.D. Chicago: W. T. Keener & Company. pp. 372 + x. Price, \$3.50.

The first 146 pages of this book are devoted to the inspection of meat, chiefly from a veterinary standpoint. Two hundred and one pages are given up to the text of the laws of Great Britain and Ireland, together with brief footnotes by the author in explanation thereof and a list of the acts given and cases cited. The book makes no reference to other conditions than those of Great Britain and Ireland, except that the text of the regulations governing meat inspection in the United States is given. On the whole, the scope of the book is not such as would be indicated by its title.

W. D. BIGELOW.

ERRATA.

Vol. 42, p. 128, footnote 4, should read: Stieglitz and Acree: *Ibid.*, 39, 529.

Vol. 42, p. 129, footnote 4, should read: Stieglitz and Acree: THIS JOURNAL, 39, 529, and Stieglitz: *Ibid.*, 39, 651.

AMERICAN CHEMICAL JOURNAL

VINYLPHENYL KETONE AND SOME OF ITS HOMOLOGUES.

BY E. P. KOHLER.

While studying the reaction between unsaturated ketones and organic magnesium compounds it was desirable to compare the behavior of benzalacetone with that of vinylphenyl ketone and its homologues. An examination of the literature showed that very few of the latter had been prepared. Moureu,¹ in the course of an admirable investigation of acrylic acid, allowed the chloride to react with benzene in the presence of aluminium chloride and obtained a very small yield of a colorless solid that he regarded as vinylphenyl ketone. This conclusion was not accepted by Klages,² who treated α -bromopropiophenone and its homologues with alcoholic potassium hydroxide and obtained yellow liquids which he assumed to be the first members of this class of ketones.

In a recent paper³ I showed that the yellow liquids described by Klages are mixtures that do not contain a trace of unsaturated compounds. This leaves the vinylphenyl ketone of

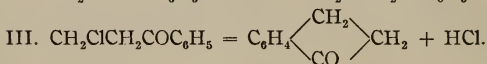
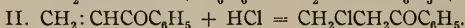
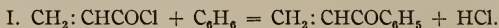
¹ Ann. Chim. Phys., [7] **2**, 198.

² Chem. Ztg., **1908**, 318.

³ THIS JOURNAL, **41**, 417.

Moureu as the only possible representative of this type of unsaturated ketone. Moureu adduced no direct evidence that his product was unsaturated. As described by him the substance seemed much too stable and unreactive to be a vinyl derivative. It was necessary, therefore, to repeat Moureu's experiment in spite of the difficulty of getting the materials and the discouragingly small yield of less than 4 per cent.

I found that the solid described by Moureu is not vinylphenyl ketone but the isomeric saturated cyclic compound, α -hydrindone. This is, doubtless, formed from vinylphenyl ketone, either by direct condensation or, more probably, by preliminary addition of hydrogen chloride to the unsaturated ketone and subsequent ring formation:



As both vinylphenyl ketone and β -chlorpropiofenone give α -hydrindone when brought in contact with aluminium chloride, it is not possible to decide between these reactions, but the halogen compound gives a much larger yield than the unsaturated ketone.

The formation of hydrindone from vinylphenyl ketone illustrates the reactivity which makes the preparation of this substance a difficult undertaking. After a number of unsuccessful attempts a possible, though far from satisfactory, method of preparation was found. This depends on the removal of bromine from α,β -dibrompropiofenone. The dibrom ketone was easily made in any desired quantity from dibrompropionyl chloride and benzene by the Friedel and Crafts reaction. The elimination of bromine proved more difficult. Zinc and alcohol gave only propiofenone and α,δ -dibenzoylbutane—obviously reduction products of the unsaturated ketone. The combination of zinc and acetone recently recommended by Straus¹ for cases in which easily reducible substances are to be expected proved equally value-

¹ Ann. Chem. (Liebig), **342**, 190.

less. The removal of halogen took place very slowly and the resulting unsaturated ketone was contaminated with such quantities of condensation products, formed by the prolonged action of zinc bromide on boiling acetone, that it was impossible to isolate a pure product.

A more satisfactory reagent was found in potassium iodide. Völker and Zolla¹ found as early as 1878 that this substance can be used for getting acrylic acid from α,β -dibrompropionic acid. Since then the reaction between potassium iodide and polyhalogen compounds that have two halogen atoms in combination with adjoining carbon atoms has been the subject of several special investigations but has found little use for the preparation of unsaturated compounds. This is due, doubtless, to the fact that in the cases studied the reaction took place very slowly and ultimately resulted in a condition of equilibrium. This is not true in the case of α,β -dibrom ketones. Preliminary experiments with benzalacetone dibromide and benzalacetophenone dibromide showed that potassium iodide dissolved in alcohol is an admirable reagent for eliminating bromine from this type of dihalogen compound; the reaction proceeded rapidly, was complete, and yielded the calculated quantity of unsaturated ketone.

That the reaction between potassium iodide and α,β -dibrompropiofenone is not so satisfactory is due solely to the reactivity of vinylphenyl ketone. In the presence of minute quantities of acid this is capable of combining with the alcohol used as medium. The product is, therefore, always a mixture of the unsaturated ketone and β -alkoxypropiofenone. This can be separated by repeated fractional distillation under diminished pressure, but the yield of unsaturated ketone is variable—from 25 to 60 per cent. of the calculated quantity. As I found no other satisfactory medium and no means of removing alcohol from ethoxypropiofenone, this was the best yield obtained.

Vinylphenyl ketone is, as was to be expected, the most reactive of all α,β -unsaturated ketones with the possible exception of the vinylalkyl ketones recently made by Blaise and Maire.²

¹ Ann. Chem. (Liebig); **192**, 102.

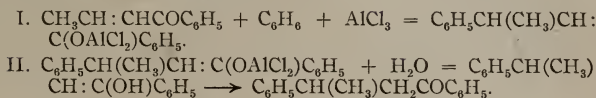
² Compt. Rend., **142**, 215.

It instantaneously reduces permanganate solutions, combines energetically with bromine, halogen acids, and primary and secondary amines, and polymerizes both when exposed to sunlight and when heated to comparatively low temperatures. The pure ketone apparently undergoes no change when boiled with pure alcohol but if a drop of aqueous hydrochloric acid be added to the liquid or if the ketone contain any impurity that, like β -chloropropiophenone, can react with alcohol to give a halogen acid, it adds alcohol more or less rapidly and passes into β -ethoxypropiophenone.

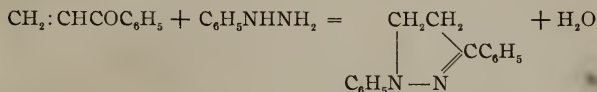
The ketone also combines readily with acid sulphites. The product with hydrogen sodium sulphite is a very soluble sodium salt of β -benzoylethanesulphonic acid that is not affected by boiling with a solution of sodium carbonate. This explains why none of the ketone was obtained by Moureu. Experiments made after the properties of the ketone were known showed that the crude product of the reaction between the chloride of acrylic acid and benzene contains variable amounts of the unsaturated ketone. Much of this is destroyed during the process of distillation, the remainder being lost by the subsequent treatment with acid sodium sulphite adopted by Moureu.

The reactions that ultimately yielded pure vinylphenyl ketone were also used for making propenylphenyl ketone and isobutenylphenyl ketone. These ketones are far less reactive than the first member of the series. They do not readily combine with alcohol and they show no tendency towards polymerization during distillation under diminished pressure. Their preparation by this method therefore presented no difficulties and the yields were satisfactory. Most of the homologues that have alkyl in place of hydrogen in the β position are, however, probably obtained more easily by the Friedel and Crafts reaction. This was tried with crotonyl chloride and benzene, and gave excellent results. The yield of propenylphenyl ketone was 90 per cent. of the calculated amount. The only other product obtained was β -phenylbutyrophenone. The formation of this substance under these conditions is interesting because it indicates that benzene and

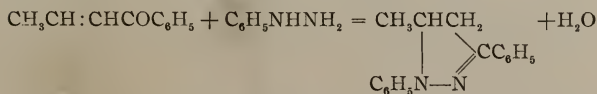
aluminium chloride may react exactly like organic magnesium compounds with unsaturated ketones:



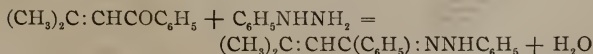
The effect of the methyl groups in the β position is shown most clearly by the behavior of these ketones towards phenylhydrazine and towards organic magnesium compounds. When an alcoholic solution of phenylhydrazine containing a few drops of acetic acid is added to a solution of vinylphenyl ketone in the same solvent, the liquid immediately becomes hot and in a few minutes all of the ketone is transformed into a pyrazoline derivative:



With propenylphenyl ketone there is no evidence of reaction at the ordinary temperature, but the corresponding pyrazoline is obtained when the mixture is boiled:



Isobutylphenyl ketone forms no pyrazoline derivative under these conditions:



The behavior of the ketones towards organic magnesium compounds is shown in the following table, in which they are grouped with a few of the most closely related compounds studied in earlier investigations. The numbers represent, in per cents., the relative amounts of 1,4-addition product formed:

Unsaturated compound.	Reagent.	
	$C_2H_5MgBr.$	$C_6H_5MgBr.$
$CH_2:CHCHO$	0	0
$CH_2:CHCOC_6H_5$	100	100
$CH_3CH:CHCOCH_3$	75	40
$CH_3CH:CHCOC_6H_5$	100	100
$C_6H_5CH:CHCOCH_3$	60	12
$C_6H_5CH:CHCOC_6H_5$	99	94
$(CH_3)_2C:CHCOCH_3$	0	0
$(CH_3)_2C:CHCOC_6H_5$.....	...	95
$(C_6H_5)_2C:CHCOC_6H_5$	18	0

EXPERIMENTAL PART.

I. Repetition of the Experiments of Moureu.

The large quantity of acrylic acid needed for these experiments was made by the method proposed by Moureu and I am able to confirm his statements that this procedure gives a perfectly pure acid. The chloride was obtained by treating the sodium salt with phosphorus oxychloride, but I found the addition of high-boiling paraffine oil, recommended by Moureu, both unnecessary and disadvantageous. When the sodium salt is dried slowly it is left as a porous powder that affords excellent contact and all that is necessary to insure a good yield of the chloride is sufficiently slow addition of the oxychloride. In the absence of paraffine oil a single redistillation of the product gives over 90 per cent. of the possible amount of pure chloride.

The reaction with benzene and aluminium chloride was carried out as directed by Moureu, and the product isolated by his method of procedure. The yield of pure solid, melting at 41° – 42° , was 12 grams from 250 grams of chloride.

The results of an analysis and a molecular weight determination agreed with those published by Moureu, but a test with potassium permanganate dissolved in acetone showed at once that the substance could not be an α,β -unsaturated ketone, because its effect on permanganate did not exceed that of acetone. As α -hydrindone is described as a colorless solid melting at 40° and forming an unstable phenylhydrazone melting at 130° —the properties of the phenylhydrazone obtained by Moureu—there seemed little room for doubt as

to the nature of the substance. α -Hydrindone was made from phenylpropionyl chloride and the melting point of a mixture of the substances compared with that of the components; all melted at the same temperature. Moureu's vinylphenyl ketone is, therefore, α -hydrindone.

II. Vinylphenyl Ketone.

The necessity of making large quantities of pure dibromopropionic acid led to a considerable improvement in the method of preparation. The addition of bromine to allyl alcohol was carried out in carbon bisulphide, but by cooling in a freezing mixture it was possible to use a much smaller quantity of solvent than was recommended by Michael and Norton¹ and to add the bromine much more rapidly without diminishing the yield. Thirteen hundred and sixty grams of dry bromine were diluted with an equal volume of carbon bisulphide and added, in less than 2 hours, to 500 grams of allyl alcohol dissolved in 2 liters of the same solvent. The bromine was delivered from dropping funnels into the alcohol contained in two flasks that were shaken in freezing mixtures. The solvent was removed by distillation as soon as a decided color of bromine remained after shaking for 10 minutes. The residue, fractioned under diminished pressure, gave 1690 grams of dibromopropyl alcohol boiling at 115°–120° (18 mm.), a yield of 91 per cent.

The mixture of concentrated and fuming nitric acid proposed by Tollens and Caspary² was used for oxidizing the alcohol to dibromopropionic acid. To avoid the sudden, energetic reaction that takes place soon after the nitric acid is added, the mixture was kept in ice water for a few hours, then overnight at the ordinary temperature. In this way it was possible to oxidize in quantities of 250 grams without loss of material. Most of the water and acid was removed, as usual, by distillation under atmospheric pressure, the remainder by heating in boiling water under greatly diminished pressure.

It has long been known that a good yield of impure dibrom-

¹ THIS JOURNAL, 2, 18.

² Ann. Chem. (Liebig), 167, 225.

propionic acid can be obtained by oxidation of dibromopropyl alcohol, but that the method of purification devised by Tollens and Munder¹ involves serious loss. Most of this can be avoided by distillation under diminished pressure. When the crude acid is heated under a pressure of 20 mm. it first yields a small quantity of low-boiling distillate, then suddenly turns red and begins to evolve oxides of nitrogen, carbon monoxide, and carbon dioxide when the temperature reaches 135°–140°. The residue left after the evolution of gases ceases is almost colorless. It begins to distil at 150° (20 mm.) and the fraction collected at 150°–160° is sufficiently pure for most purposes, but contains small quantities of nitric acid derivatives and some polymeric product. On redistillation it yields a small quantity of nitric acid and leaves a residue of non-volatile material. The fraction collected at 155°–158° boils constantly, when distilled again, at 160° (20 mm.)—the boiling point of pure α,β -dibromopropionic acid. The yield was 1387 grams of pure acid from 1690 grams of dibromopropyl alcohol—76 per cent. of the calculated amount.

Dibromopropionic acid reacts very slowly with phosphorus trichloride and it is necessary to heat for 12 hours to complete the reaction. The acid chloride was easily obtained, however, by suspending the acid in a small quantity of phosphorus oxychloride, cooling the mixture in ice water, and adding the calculated quantity of phosphorus pentachloride in small quantities. The resulting liquid was fractioned under diminished pressure. A considerable quantity of the chloride distils with the oxychloride, but this is easily recovered by removing most of the oxychloride from this fraction by distillation under ordinary pressure and then redistilling the remainder under diminished pressure. The properties of the chloride were the same as those found by Moureu in a product obtained by adding bromine to the chloride of acrylic acid.

Dibromopropiophenone, $\text{CH}_2\text{BrCHBrCOC}_6\text{H}_5$.—To prepare this ketone 250 grams of dibromopropionyl chloride and 100 grams of benzene were dissolved in 500 cc. of carbon bisulphide and the solution cooled in a freezing mixture. Ground aluminium

¹ Ann. Chem. (Liebig), **167**, 240.

chloride was then added, in 10–20 gram quantities, until further addition no longer produced rapid evolution of hydrogen chloride—150 to 160 grams. The reaction is a remarkably clean one, because a colorless aluminium derivative of the ketone separates from the liquid and thus escapes further change. The product was immediately poured into a mixture of ice and concentrated hydrochloric acid, the carbon bisulphide layer drawn into a shallow dish, and the solvent allowed to evaporate. This left a colorless solid and a small quantity of a pale yellow oil. The oil was removed with a pump, the solid washed thoroughly—first with water, then with small quantities of absolute alcohol—and purified by crystallization from alcohol or low-boiling ligroin. The yield was excellent: 250 grams of chloride gave 290 grams of crude and 278 grams of pure ketone—95 per cent. of the calculated amount.

Analysis:

0.1525 gram substance gave 0.2047 gram CO_2 and 0.0411 gram H_2O .

	Calculated for $\text{C}_9\text{H}_8\text{OBr}_2$.	Found.
C	36.9	36.6
H	2.7	3.0

α,β -Dibromopropiophenone crystallizes in large needles or plates melting at 58° . It is readily soluble in ether, acetone, and boiling alcohol, moderately in cold alcohol and ligroin.

Reaction with Zinc.—For the purpose of eliminating bromine, a little more than the calculated quantity of zinc dust was added in small quantities to a solution of 100 grams of the bromketone in 500 cc. of alcohol. After boiling for an hour most of the alcohol was removed by distillation and the residue poured into water. This precipitated an oil that partially solidified on standing. The solid was removed and a small quantity tested with bromine in a freezing mixture, but no unsaturated ketone was found. The oil was, therefore, dried and distilled under diminished pressure. The distillate was pure propiophenone, identified by its boiling point and the melting point of its oxime.

The solid that separated when the alcoholic residue was poured into water was purified by crystallization from a mixture of chloroform and alcohol. It separated in small prisms that melted at 112° .

Analysis:

0.1295 gram substance gave 0.3816 gram CO_2 and 0.0815 gram H_2O .

	Calculated for $\text{C}_{18}\text{H}_{18}\text{O}_2$.	Found.
C	81.2	81.4
H	6.7	7.0

The molecular weight was determined in carbon tetrachloride ($k = 48$).

Solvent. Grams.	Substance. Gram.	Elevation of boiling point.	Molecular weight.
56.1	0.3210	0.090	282
56.1	0.5305	0.147	309
56.1	0.7510	0.220	292
Calculated for $\text{C}_{18}\text{H}_{18}\text{O}_2$,			266

When boiled with an alcoholic solution of hydroxylamine hydrochloride and an excess of potassium hydroxide, the substance gave a very sparingly soluble dioxime. This was purified by recrystallization from amyl alcohol, from which it separated in minute needles melting at 232° .

Analysis:

0.1431 gram substance gave 0.3815 gram CO_2 and 0.0884 gram H_2O .

	Calculated for $\text{C}_{18}\text{H}_{20}\text{O}_2\text{N}_2$.	Found.
C	73.0	72.7
H	6.7	6.8

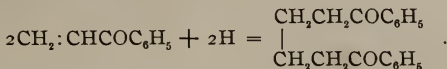
Eight grams of the dioxime were treated with phosphorus pentachloride in absolute ether, the product boiled with water, and the resulting solid heated at 160° with concentrated hydrochloric acid for 8 hours. From the acid solution ether extracted 1.8 grams of an acid that melted at 149° after one crystallization from water.

Analysis:

0.2011 gram substance gave 0.3627 gram CO₂ and 0.1285 gram H₂O.

	Calculated for C ₆ H ₁₀ O ₄ .	Found.
C	49.3	49.2
H	6.9	7.2

The substance is adipic acid. The solid melting at 112° is, therefore, dibenzoylbutane, a dimolecular reduction product of vinylphenyl ketone:



This ketone was made by Étaix¹ from the chloride of adipic acid and benzene, by the Friedel and Crafts reaction. Étaix gives 102° as the melting point of the ketone and 218° as the melting point of the oxime, but he evidently did not have pure substances, as his ketone was colored and he made no attempt to purify the oxime.

The formation of these two reduction products of vinylphenyl ketone—propiophenone and dibenzoylbutane—in the presence of a large quantity of unchanged dibromketone, showed that it was hopeless to attempt to remove the bromine with metals in the presence of alcohol. Acetone was therefore substituted for alcohol as the solvent. In acetone the zinc disappears very slowly; it was necessary to boil for 8 hours to get a product fairly free from bromine. This product undoubtedly contained some unsaturated ketone, since it was possible, by vacuum distillation, to separate a fraction that was free from bromine and that gave α,β -dibrompropiophenone when treated with bromine in a freezing mixture. The amount of vinylphenyl ketone present was, however, relatively small and it was impossible to free it from the numerous condensation products of acetone with which it was mixed.

Reaction with Potassium Iodide.—In a flask connected with an inverted condenser 120 grams of powdered potassium iodide were partially dissolved in 500 cc. of boiling alcohol.

¹ Ann. Chim. Phys., [7] 9, 372.

To this solution 100 grams of the bromketone were added in small portions. The mixture was boiled for two hours, then cooled and poured into a solution containing an excess of sodium thiosulphate. The solution was extracted with ether, the ethereal solution dried with fused sodium sulphate, and the alcohol and ether removed by distillation. The residue—a yellow liquid that did not solidify in a freezing mixture—was distilled under diminished pressure. It gave a colorless distillate boiling at 105° – 135° (18 mm.). A test with bromine showed that nearly half of this distillate was vinylphenyl ketone. The experiment was, therefore, repeated in order to accumulate sufficient material with which to undertake a separation. Five hundred grams of dibromopropiophenone gave 208 grams of this colorless liquid. By repeated fractional distillation under diminished pressure, two pure substances were finally obtained from it.

Vinylphenyl Ketone, $\text{CH}_2 : \text{CHCOC}_6\text{H}_5$.—The unsaturated ketone accumulated in the lower-boiling fractions. When perfectly pure it boiled constantly at 115° (18 mm.). The purity was established by analysis and by a test with bromine which, in this case, is more conclusive than the results of analyses.

Analysis:

0.1340 gram substance gave 0.4009 gram CO_2 and 0.0729 gram H_2O .

	Calculated for $\text{C}_9\text{H}_8\text{O}$.	Found.
C	81.8	81.6
H	6.1	6.0

The molecular weight was determined in benzene ($k = 50$).

Solvent. Grams.	Substance. Gram.	Depression of freezing point.	Molecular weight.
12.0	0.1640	0.500	137
12.0	0.2205	0.634	145
12.0	0.3500	1.086	134
Calculated for $\text{C}_9\text{H}_8\text{O}$,			132

In order to test the purity of the substance, 2 grams were dissolved in freshly distilled carbon bisulphide, and the solution cooled in a freezing mixture and treated with a solution of pure,

dry bromine in the same solvent until a faint color of bromine appeared in the liquid. When the solvent was evaporated under diminished pressure it left pure dibromopropiophenone. The liquid boiling at 115° (18 mm.) was, therefore, pure vinylphenyl ketone. The yield was 78 grams from 500 grams of dibromopropiophenone.

Vinylphenyl ketone is an unstable substance. When kept in sealed tubes in the dark it changes very slowly, but ultimately becomes discolored and viscous. The same or a similar change takes place much more rapidly in the light, and when the substance is exposed to light and air the change is accompanied by oxidation with formation of formaldehyde as one of the products. A small quantity of nonvolatile matter is left after each distillation under diminished pressure and when the ketone is kept at 115° —the boiling point under a pressure of 18 mm.—it soon becomes yellow. When heated rapidly in a bath under atmospheric pressure it begins to change perceptibly at 120° , then suddenly boils and decomposes when the temperature of the bath reaches 150° – 160° , the heat evolved being sufficient to raise the temperature of the substance above 200° . A similar sudden transformation occasionally takes place when the ketone is exposed to direct sunlight.

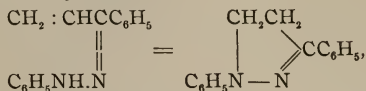
Diphenylhydrazine, $C_{15}H_{14}N_2$.—Vinylphenyl ketone reacts energetically with phenylhydrazine. Three grams of the ketone were poured into a solution of an equal weight of the base in 10 cc. of alcohol, to which a few drops of glacial acetic acid had been added. The liquid immediately became hot and in a very short time most of the product had separated in crystalline form. It was washed with alcohol and recrystallized from absolute alcohol. It separates in large yellow needles, melting at 158° . It is sparingly soluble in alcohol and ether.

Analysis:

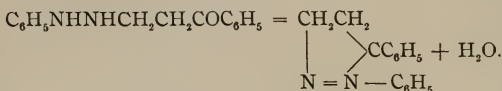
0.1572 gram substance gave 0.4700 gram CO_2 and 0.0915 gram H_2O .

	Calculated for $C_{15}H_{14}N_2$.	Found.
C	81.1	81.5
H	6.3	6.5

As vinylphenyl ketone combines energetically with primary amines, this substance may be either 1,3-diphenylpyrazoline, formed from the hydrazone,



or 1,5-diphenylpyrazoline formed from an addition product,



By analogy with the product obtained from crotonic aldehyde the former would be expected, but as the aldehyde contains a much more reactive carbonyl group than the ketone, this method of reasoning is not conclusive.

Ethoxypropiofenon, $\text{C}_2\text{H}_5\text{OCH}_2\text{CH}_2\text{COC}_6\text{H}_5$.—This substance was the second product of the reaction between potassium iodide and dibrompropiofenon, in alcoholic solution. It is easily made by dissolving vinylphenyl ketone in alcohol, adding a few drops of hydrochloric acid, and boiling for a short time, and also by boiling β -chlorpropiofenon with alcoholic potassium hydroxide. It is a colorless liquid that boils at 135° (18 mm.), solidifies in a freezing mixture, and then melts at about 12° .

Analysis:

0.1421 gram substance gave 0.3883 gram CO_2 and 0.1023 gram H_2O .

	Calculated for $\text{C}_{11}\text{H}_{14}\text{O}_2$.	Found.
C	74.2	74.5
H	7.8	8.0

Ethoxypropiofenon phenylhydrazone was made by boiling the ketone with phenylhydrazine in alcoholic solution and recrystallizing the product from methyl alcohol. It crystallizes in very pale yellow plates that melt at 86° . It is readily soluble in alcohol and ether, moderately in methyl alcohol and ligroin.

Analysis:

0.1580 gram substance gave 0.4428 gram CO_2 and 0.1070 gram H_2O .

	Calculated for $\text{C}_{17}\text{H}_{20}\text{ON}_2$.	Found.
C	76.1	76.4
H	7.5	7.5

β -Chlorpropioiophenone, $\text{ClCH}_2\text{CH}_2\text{COC}_6\text{H}_5$.—Vinylphenyl ketone absorbs gaseous hydrogen chloride and forms β -chlorpropioiophenone. A pure product is obtained by saturating a cooled solution of the ketone in absolute ether with hydrogen chloride and allowing the solvent to evaporate. It is a colorless solid that crystallizes in large plates, melting at 57° . It is readily soluble in all common organic solvents except low-boiling ligroin.

Analysis:

0.1991 gram substance gave 0.4672 gram CO_2 and 0.0927 gram H_2O .

	Calculated for $\text{C}_9\text{H}_9\text{OCl}$.	Found.
C	64.1	64.0
H	5.3	5.2

When the chlorketone is heated under diminished pressure (20 mm.) it begins to lose hydrogen chloride and distil freely at about 120° . About 25 per cent. of the material is left as a brown, nonvolatile residue. The distillate is composed of variable quantities of unchanged substance and vinylphenyl ketone.

Sodium Benzoylethanesulphonate,

$\text{C}_6\text{H}_5\text{COCH}_2\text{CH}_2\text{SO}_3\text{Na.H}_2\text{O}$.—Vinylphenyl ketone combines readily with acid sulphites. When the pure ketone was warmed with a saturated solution containing slightly more than the calculated quantity of sodium hydrogen sulphite, a rapid reaction commenced at 50° , the oily ketone dissolving in a few minutes while the temperature rose to the boiling point of the solution. On cooling the liquid, the addition product separated in large colorless plates. The salt is readily soluble in water. It crystallizes with one molecule of water, which it loses below 100° .

Analysis:

I. 0.2297 gram salt lost 0.0158 gram at 120° and the residue gave 0.0649 gram Na_2SO_4 .

II. 0.2322 gram salt lost 0.0162 gram at 120° and the residue gave 0.0640 gram Na_2SO_4 .

	Calculated for $\text{C}_9\text{H}_9\text{O}_4\text{SN a. H}_2\text{O}$.	I.	Found.	II.
H_2O	7.09	6.86		6.97
Na	9.74	9.75		9.60

The sodium salt is not decomposed either by sodium carbonate or by dilute acids.

β -Benzoylethanesulphonic Acid, $\text{C}_6\text{H}_5\text{COCH}_2\text{CH}_2\text{SO}_3\text{H}$.—In order to compare the properties of the chloride of a γ -keto-sulphonic acid with that of ethanedisulphonic acid, which forms an unsaturated compound when boiled with water, an attempt was made to transform the sodium salt into the sulphone chloride. The reaction with phosphorus pentachloride is so vigorous that the principal product is β -chlor-propiophenone—formed by elimination of the sulphonic acid group. The dry sodium salt was, therefore, suspended in phosphorus oxychloride, the mixture cooled in ice water and treated with the calculated quantity of the pentachloride, added in small amounts. The oxychloride was then removed by distillation under diminished pressure. The residue solidified completely. It undoubtedly contained the sulphone chloride. But when it was poured into ice water and the resulting solid dried and recrystallized from chloroform, the crystals that separated were pure acid.

Analysis:

0.1628 gram substance gave 0.3048 gram CO_2 and 0.0732 gram H_2O .

	Calculated for $\text{C}_9\text{H}_{10}\text{O}_4\text{S}$.	Found.
C	50.5	51.0
H	4.7	5.0

The acid is readily soluble in water and alcohol, moderately in chloroform, insoluble in ether. It separates from chloroform in colorless needles, melting at 95° . From cold, concentrated water solutions it separates with water of crystallization, but the anhydrous acid is left when water solutions

are evaporated on a steam bath. When the acid is heated under diminished pressure it loses water and sulphur dioxide above 120° . A small quantity of vinylphenyl ketone is formed, but the principal product is the brown, nonvolatile residue that always results from superheating the unsaturated ketone.

Reaction with Organic Magnesium Compounds.—The unsaturated ketone was allowed to react with methylmagnesium iodide and phenylmagnesium bromide in ethereal solution. The products were isolated as described in earlier papers. In each case a test for unsaturated compounds was made by treating a part of the product with a solution of potassium permanganate in acetone, and in each case the result was negative. The only substance obtained with methylmagnesium iodide was normal propylphenyl ketone, which was identified by its boiling point— 225° —and by the melting point of the semicarbazone— 188° . Phenylmagnesium bromide gave only β -phenylpropiophenone, identified by its melting point, 72° , and by comparison with a specimen on hand. The reaction between vinylphenyl ketone and organic magnesium compounds, therefore, consists exclusively in 1,4-addition:



α,β -Dibromomethyl-4-bromophenyl Ketone,

$\text{CH}_2\text{BrCHBrCO}_6\text{H}_4\text{Br}$.—This ketone was used in the hope of getting a solid unsaturated ketone. It was made from dibromopropionyl chloride and brombenzene by the Friedel and Crafts reaction. The procedure was exactly the same as that used for making dibromopropiophenone and the yield was equally good. The ketone is much more soluble in organic solvents than dibromopropiophenone. It separates from alcohol and from ligroin in large prisms or tables, melting at 74° .

Analysis:

0.2122 gram substance gave 0.2272 gram CO_2 and 0.0401 gram H_2O .

	Calculated for $\text{C}_9\text{H}_7\text{OBr}_3$.	Found.
C	29.1	29.2
H	1.9	2.1

β-Ethoxyethyl-4-bromphenyl Ketone,

$C_2H_5OCH_2CH_2COC_6H_4Br$.—The reaction between the bromketone and potassium iodide was carried out as in the case of dibrompropiofenone. The colorless oil that separated when the product was poured into a solution of sodium thiosulphate partially solidified on standing. The solid was separated and recrystallized from alcohol, from which it separated in large colorless plates, melting at 54° .

Analysis:

0.1940 gram substance gave 0.3669 gram CO_2 and 0.0883 gram H_2O .

	Calculated for $C_{11}H_{13}O_2Br$.	Found.
C	51.4	51.6
H	5.1	5.2

The substance is readily soluble in all common organic solvents except low-boiling ligroin.

The *phenylhydrazone*, $C_2H_5OCH_2CH_2C(C_6H_5) : NNHC_6H_5$, crystallizes from alcohol in pale yellow plates, melting at 108° . It is readily soluble in ether, moderately in alcohol.

Analysis:

0.2004 gram substance gave 0.4321 gram CO_2 and 0.1028 gram H_2O .

	Calculated for $C_{17}H_{19}ON_2Br$.	Found.
C	58.8	58.8
H	5.5	5.7

The oil formed along with ethoxyethylbromphenyl ketone in the reaction with potassium iodide was tested with bromine and found to consist mainly of unsaturated ketone. An attempt to distil it under diminished pressure, after it had been dried in ethereal solution, resulted in complete decomposition. In a second experiment the oil was freed as far as possible from ethoxy compound before distillation. For this purpose a part of it was dissolved in low-boiling ligroin and the solution cooled in a freezing mixture in contact with some of the solid ethoxy compound. The test with bromine showed that 91 per cent. of the liquid left after removing the solid and evaporating the ligroin was vinylbromphenyl ketone, but

this product also decomposed below the boiling point under 18 mm. pressure. The remainder of the liquid was distilled with steam. The first distillates were rich in unsaturated ketone, but likewise decomposed before distillation.

III. Propenylphenyl Ketone.

Dibrombutyryl Chloride, $\text{CH}_3\text{CHBrCHBrCOCl}$.—The starting point in the preparation of propenylphenyl ketone was the solid crotonic acid. This was treated with bromine and the resulting dibrombutyric acid transformed into the chloride without previous purification. The yield of the latter was excellent—298 grams of pure chloride from 100 grams of crotonic acid. The chloride is a colorless liquid boiling at 112° (20 mm.).

Analysis:

- I. 0.1231 gram substance gave 0.2446 gram silver halide.
 II. 0.1120 gram substance gave 0.2224 gram silver halide.

	Calculated for $\text{C}_4\text{H}_5\text{OBr}_2\text{Cl}$.	I.	Found.	II.
BrCl	74.9	75.3		75.0

Dibrombutyrophenone, $\text{CH}_3\text{CHBrCHBrCOC}_6\text{H}_5$.—The bromketone was made and purified like dibrompropiofenone. It crystallizes in needles and melts at 112° .

Analysis:

0.1615 gram substance gave 0.2311 gram CO_2 and 0.0480 gram H_2O .

	Calculated for $\text{C}_{10}\text{H}_{10}\text{OBr}_2$	Found.
C	39.2	39.0
H	3.3	3.3

see errata p. 588

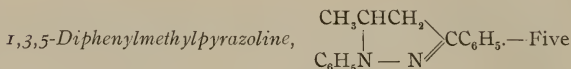
Propenylphenyl Ketone, $\text{CH}_3\text{CH}:\text{CHCOC}_6\text{H}_5$.—The reaction between the bromketone and potassium iodide was carried out as in previous cases, but as the ethereal solution of the unsaturated ketone extracts a compound containing sulphur and iodine from the solution in which iodine is removed with thiosulphate, it was found to be better to adopt a different method of isolating the unsaturated ketone. The alcoholic solution was poured into an excess of thiosulphate and the ketone extracted with ether as in previous cases. The ether was re-

moved and the residue distilled with steam before the distillation under diminished pressure. The ketone was then separated from the aqueous distillates, dried in ethereal solution with calcium chloride and distilled under diminished pressure. A single distillation gave a colorless liquid boiling constantly at 135° (20 mm.). The test with bromine showed that this was pure propenylphenyl ketone. The yield was 90 per cent. of the calculated amount.

Analysis:

0.1242 gram substance gave 0.3730 gram CO_2 and 0.0775 gram H_2O .

	Calculated for $\text{C}_{10}\text{H}_{10}\text{O}$.	Found.
C	82.2	81.9
H	6.8	6.9



grams of phenylhydrazine were added to an equal weight of ketone dissolved in 25 cc. of alcohol to which a few drops of glacial acetic acid had been added. As there was no evidence of action at the ordinary temperature the mixture was boiled for several hours. The pyrazoline separated in thin yellow plates when the liquid was allowed to cool. It was washed with alcohol and recrystallized from absolute alcohol. It melts at 108° , is sparingly soluble in alcohol and acetone, readily in ether. The solutions in alcohol show a green fluorescence.

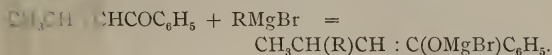
Analysis:

0.1211 gram substance gave 0.3615 gram CO_2 and 0.0770 gram H_2O .

	Calculated for $\text{C}_{16}\text{H}_{16}\text{N}_2$.	Found.
C	81.3	81.4
H	6.8	7.1

Reaction with Organic Magnesium Compounds.—The ketone was allowed to react with methylmagnesium iodide and phenylmagnesium bromide. The products were isolated in the usual way and tested for unsaturated compounds with potassium

peroxide dissolved in acetone. No unsaturated compound was formed in either case. The only substance formed when phenylmagnesium iodide was used was isovalerophenone, recognized by its boiling point—226°—and the melting point of its oxime. Similarly, phenylmagnesium bromide gave only 2-phenylbutyrophenone, identified by comparison with a specimen on hand. The reaction between propenylphenyl ketone and organic magnesium compounds, therefore, consists exclusively of 1,4-addition to the unsaturated ketone:



Propenyl Chloride, $\text{CH}_3\text{CH} : \text{CHCOCl}$.—In view of the great difference in activity of vinylphenyl ketone and propenylphenyl ketone it seemed worth while to undertake the preparation of the latter by the Friedel and Crafts reaction. To this end acrylic acid was neutralized with sodium carbonate, and the sodium salt dried to constant weight at 135° and treated with phosphorus oxychloride as described in the preparation of the chloride of acrylic acid. The yield of chloride was good, 15 grams of pure product from 100 grams of sodium salt. The chloride is a colorless liquid boiling at 126°.

Analysis:

- I. 0.1111 gram substance gave 0.1820 gram AgCl .
 II. 0.1330 gram substance gave 0.1638 gram AgCl .

	Calculated for $\text{C}_6\text{H}_5\text{OCl}$.	I.	Found. II.
Cl	34.0	34.3	34.3

A little more than the calculated amount of finely ground aluminium chloride was added gradually to a solution of 50 grams of propenyl chloride and 50 grams of benzene in 150 cc. of carbon disulphide that was cooled in a freezing mixture. The aluminium chloride dissolved rapidly without producing any evolution of gas. The vessel containing the solution was then placed in ice water and exposed to direct sunlight. This started brisk evolution of hydrogen chloride and deposition of a colorless crystalline aluminium derivative. The reaction was complete after exposure for 15 min-

utes. The product was poured into iced acid, the substances extracted with ether, dried, and distilled under diminished pressure after the solvents had been removed. The liquid began to boil at 135° (20 mm.) and most of the product distilled at 135° – 140° . The temperature then rose rapidly and a second colorless distillate was collected at 175° and 185° . Less than half a gram of residue remained in the distilling flask.

A test with bromine showed that the first distillate was the most pure propenylphenyl ketone. On redistillation 44 grams of pure ketone.

The second distillate (175° – 185°) solidified on cooling. It was recrystallized from methyl alcohol and was obtained in large colorless plates, melting at 74° .

Analysis:

0.1306 gram substance gave 0.4098 gram CO_2 and 0.0790 gram H_2O .

	Calculated for $\text{C}_{16}\text{H}_{16}\text{O}$.
C	85.8
H	7.2

The composition indicated a compound formed by addition of benzene to propenylphenyl ketone and by comparison with a specimen on hand the substance was identified as dibenzylbutyrophenone, $\text{C}_6\text{H}_5\text{CH}(\text{CH}_3)\text{CH}_2\text{COC}_6\text{H}_5$. As the results of this experiment show, this is a much better method for identifying the unsaturated ketone.

Propenylbromphenyl Ketone, $\text{CH}_3\text{CH}:\text{CHCO}$. For the preceding experiment was repeated, but with the use of bromobenzene in place of benzene. The product gave a distillate boiling at 160° – 180° (20 mm.) from a mixture of crotonyl chloride. The colorless liquid solidified on cooling to a mixture. The solid was recrystallized from methyl alcohol.

Analysis:

0.1611 gram substance gave 0.3135 gram CO_2 and 0.0335 gram H_2O .

	Calculated for $\text{C}_{10}\text{H}_9\text{OBr}$.
C	53.3
H	4.0

The ketone liquefies in contact with organic solvents but can be recrystallized by cooling its solution in methyl alcohol or ligroin in a freezing mixture. It separates in large, colorless tables and melts at 47°.

1,5,3-Phenylmethylbromophenylpyrazoline,

$\text{CH}_3\text{CHCH}_2 \searrow \text{CC}_6\text{H}_4\text{Br}$, the product of the reaction between
 $\text{C}_6\text{H}_5\text{N} - \text{N} =$
the unsaturated ketone and phenylhydrazine, crystallizes in yellow plates melting at 136°. Its solutions have a much more pronounced fluorescence than those of the corresponding bromine-free compound.

Analysis:

0.1331 gram substance gave 0.2980 gram CO_2 and 0.0620 gram H_2O .

	Calculated for $\text{C}_{16}\text{H}_{16}\text{N}_2\text{Br}$.	Found.
C	60.9	61.0
H	4.8	5.2

α,β -Dibromobutyl-4-bromophenyl Ketone,

$\text{CH}_3\text{CHBrCHBrCOCC}_6\text{H}_4\text{Br}$, formed by addition of bromine to the unsaturated ketone, crystallizes from methyl alcohol in needles melting at 76°. It is readily soluble in all common organic solvents except low-boiling ligroin.

Analysis:

0.1802 gram substance gave 0.2040 gram CO_2 and 0.0422 gram H_2O .

	Calculated for $\text{C}_{10}\text{H}_9\text{OBr}_3$.	Found.
C	31.2	30.9
H	2.3	2.6

IV. Isobutenylphenyl Ketone.

Dibromisovaleryl Chloride, $(\text{CH}_3)_2\text{CBrCHBrCOCl}$. — The starting point in the preparation of isobutenylphenyl ketone was β,β -dimethylacrylic acid, which was made in part from isovaleric acid, in part by the much quicker method of Barbier and Léser.¹ The calculated amount of bromine was added

¹ Bull. Soc. Chim., [3] 33, 815 (1905).

to the acid dissolved in carbon bisulphide, the solvent removed under diminished pressure, and the residue transformed into chloride as in other similar cases. The chloride is much more sensitive than those previously described. To get a good yield it is necessary to carry out the reaction at the lowest possible temperature and to avoid the least excess of phosphorus pentachloride. Under these conditions the yield is satisfactory: 228 grams of chloride of the dibrom acid from 100 grams of the unsaturated acid. The chloride is a colorless liquid boiling at 126° – 130° (20 mm.).

Analysis:

0.1210 gram substance gave 0.2275 gram silver halide.

	Calculated for $C_5H_7OClBr_2$.	Found.
BrCl	70.6	70.6

Dibromisovalerophenone, $(CH_3)_2CBrCHBrCOC_6H_5$.—Considerable care is necessary in the preparation of this substance by the Friedel and Crafts reaction. The aluminium chloride derivative of the ketone is much more readily soluble in carbon bisulphide than those previously described, hence the reaction easily leads to secondary products formed by elimination of hydrogen bromide. By keeping the temperature as low as possible and decomposing the aluminium compounds as soon as the first rapid evolution of hydrogen chloride stops, it is possible to get a fairly good yield. The ketone was recrystallized from methyl alcohol. It separated in needles melting at 81° . The yield was 206 grams of pure ketone from 200 grams of chloride.

Analysis:

0.1552 gram substance gave 0.2330 gram CO_2 and 0.0570 gram H_2O .

	Calculated for $C_{11}H_{12}OBr_2$.	Found.
C	41.2	40.9
H	3.8	4.0

Isobutenylphenyl Ketone, $(CH_3)_2C : CHCOC_6H_5$.—The reaction between the bromketone and potassium iodide was carried out like that with other bromketones and the product

isolated as described under propenylphenyl ketone. The yield of unsaturated ketone was much smaller than that of propenylphenyl ketone—only 60 per cent. of the possible amount.

Analysis:

0.1405 gram substance gave 0.4250 gram CO_2 and 0.0978 gram H_2O .

	Calculated for $\text{C}_{11}\text{H}_{12}\text{O}$.	Found.
C	82.5	82.5
H	7.5	7.7

Isobutenylphenyl ketone is a colorless liquid that boils at 148° (22 mm.). While far less reactive than any other of the unsaturated ketones described in this paper, it is, nevertheless, considerably more reactive than β -phenylbenzalacetophenone, which differs from it only in having 2 phenyl in place of 2 methyl groups. Thus it immediately reduces a cold solution of potassium permanganate in acetone and combines with bromine at the temperature of a freezing mixture—two reactions that do not take place at all with the corresponding phenyl compound.

The *phenylhydrazone* of the ketone was made in the usual way. It crystallizes in almost colorless plates melting at 88° . It is extremely unstable, turning brown and liquefying in the course of a few hours when exposed to light and air, and in a few days when sealed up and kept in the dark.

Analysis:

0.1165 gram substance gave 0.3494 gram CO_2 and 0.0754 gram H_2O .

	Calculated for $\text{C}_{17}\text{H}_{18}\text{N}_2$.	Found.
C	81.6	81.8
H	7.2	7.2

Reaction with Phenylmagnesium Bromide.—The reaction was carried out in the usual way. A test with permanganate showed the presence of unsaturated compounds in the product. It was, therefore, distilled with steam until free from bromobenzene and diphenyl, dissolved in ether, dried and frac-

tionated under diminished pressure. It first yielded a small quantity of distillate boiling between 165° and 170° , then the temperature rose rapidly to 185° – 187° , where the remainder distilled without leaving a residue. The high-boiling fraction was β -phenylisobutyrophenone.

Analysis:

0.1254 gram substance gave 0.3922 gram CO_2 and 0.0869 gram H_2O .

	Calculated for $\text{C}_{17}\text{H}_{18}\text{O}$.	Found.
C	85.7	85.3
H	7.6	7.7

The *phenylhydrazone* of the ketone crystallizes in large yellow needles melting at 94° .

Analysis:

0.1212 gram substance gave 0.3732 gram CO_2 and 0.0796 gram H_2O .

	Calculated for $\text{C}_{23}\text{H}_{24}\text{N}_2$.	Found.
C	84.0	84.1
H	7.3	7.3

Oximes.—When boiled with hydroxylamine hydrochloride and excess of potassium hydroxide in alcoholic solution, phenylisobutyrophenone formed two oximes that were separated by crystallization from a mixture of ether and ligroin. One crystallizes in needles melting at 85° , the other in plates melting at 111° . Both are readily soluble in alcohol and ether, sparingly in ligroin.

Analysis:

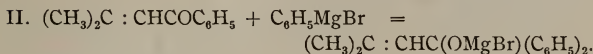
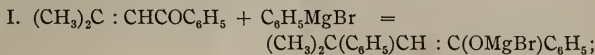
I. 0.1354 gram substance (85°) gave 0.3986 gram CO_2 and 0.0914 gram H_2O .

II. 0.1489 gram substance (111°) gave 0.4373 gram CO_2 and 0.1015 gram H_2O .

	Calculated for $\text{C}_{17}\text{H}_{19}\text{ON}$.	I.	Found.	II.
C	80.6	80.3		80.2
H	7.5	7.5		7.6

The low-boiling fraction obtained from the product of the reaction between phenylmagnesium bromide and isobutenyl-

phenyl ketone proved to be a mixture. As it was too small in amount for successful separation it was dissolved in acetone and oxidized with permanganate. The acetone was then removed completely by heating under diminished pressure and the residue distilled with steam. This gave 0.8 gram of benzophenone, proving that the unsaturated compound was due to 1,2-addition to carbonyl. Isobutenylphenyl ketone, therefore, gives two reactions with phenylmagnesium bromide:



CHEMICAL LABORATORY,
BRYN MAWR COLLEGE,
July, 1909.

[Contribution from the Kent Chemical Laboratory of the University of Chicago.]

ON THE ACTION OF FEHLING'S SOLUTION ON GALACTOSE.

BY ERNEST ANDERSON.

The following pages give a detailed account of a quantitative investigation carried out by myself, at the suggestion and under the direction of Dr. Nef, of the products formed in the oxidation of *d*-galactose by alkaline solutions containing cupric hydroxide (Fehling's solution).

It was found here, as in the case of *d*-glucose, *d*-mannose and *d*-fructose by Nef,¹ that the reaction products are, besides isomeric hexonic acids, carbonic, formic, oxalic, glycollic *d*- and *l*-glycerinic, *l*-threonic, and *d*-erythronic acids. Whereas the members of the *d*-glucose series give much *d*-gluconic and smaller amounts of *d*-mannonic acid, and also probably some α -oxymethyl-*d*-arabonic acid, which was overlooked by Nef² in his work, *d*-galactose was found to give much *d*-galactonic and relatively smaller amounts of *d*-talonic acid on treatment with the reagent named; it is highly probable

¹ Ann. Chem. (Liebig), **357**, 259-286.

² Cf. Ann. Chem. (Liebig), **357**, 298, and thesis of Spoehr, soon to be published.

also that in addition small amounts of α -oxymethyl-*d*-lyxonic acid are formed, but I was unable to prove this by experiment. It is evident also, from my work, that only two of the four possible trioxybutyric acids are formed on treatment of the above named hexoses with alkaline cupric hydroxide—namely, *l*-threonic and *d*-erythronic acids. Furthermore, Dr. Nef tells me he is now convinced, because of my work, that he overestimated the amount of trioxybutyric acids and underestimated the amount of *d*- and *l*-glycerinic acids formed when the ordinary hexoses are treated with Fehling's solution, owing to the difficulty of effecting a sharp separation of these acids.

To summarize: The following acids are the reaction products

formed by treating *d*-galactose, $\text{OCH} \begin{array}{c} \text{OH} \text{ H} \text{ H} \text{ OH} \\ | \quad | \quad | \quad | \\ \text{H} \text{ OH} \text{ OH} \text{ H} \end{array} \text{CH}_2\text{OH},$

with Fehling's solution: Carbonic; formic; oxalic glycollic, $\text{COOH} \cdot \text{CH}_2\text{OH}$; *d*- and *l*-glycerinic, $\text{COOH} \cdot \text{CHOH} \cdot \text{CH}_2\text{OH}$;

l-threonic, $\text{COOH} \begin{array}{c} \text{H} \text{ OH} \\ | \quad | \\ \text{OH} \text{ H} \end{array} \text{CH}_2\text{OH}$;

d-erythronic, $\text{COOH} \begin{array}{c} \text{OH} \text{ OH} \\ | \quad | \\ \text{H} \text{ H} \end{array} \text{CH}_2\text{OH}$;

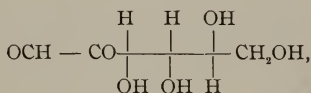
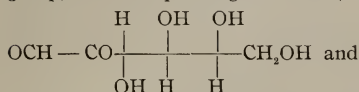
d-galactonic, $\text{COOH} \begin{array}{c} \text{OH} \text{ H} \text{ H} \text{ OH} \\ | \quad | \quad | \quad | \\ \text{H} \text{ OH} \text{ OH} \text{ H} \end{array} \text{CH}_2\text{OH}$;

d-talonic, $\text{COOH} \begin{array}{c} \text{H} \text{ H} \text{ H} \text{ OH} \\ | \quad | \quad | \quad | \\ \text{OH} \text{ OH} \text{ OH} \text{ H} \end{array} \text{CH}_2\text{OH}$;

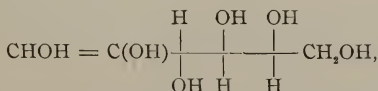
and α -oxymethyl-*d*-lyxonic, $\text{COOH} \begin{array}{c} \text{CH}_2\text{OH} \text{ H} \text{ OH} \\ | \quad | \quad | \\ \text{OH} \text{ OH} \text{ H} \end{array} \text{CH}_2\text{OH}.$

In view of all these facts and also especially because of his work on the action of soluble alkaline hydroxides on all possible sugars containing from one to six carbon atoms, which will be published in detail in *Liebig's Annalen*, in 1910, Dr. Nef now considers the following interpretation of the action of Fehling's solution on the ordinary hexoses as the final one; it is really based entirely on the ideas presented in his former paper published in 1907.¹

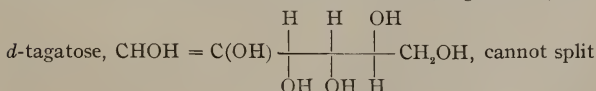
The members of the *d*-glucose and *d*-galactose series give, by oxidation of the alcohol group adjacent to the carbonyl group, the corresponding hexosones,



which then give, by the benzilic acid rearrangement, the two corresponding hexonic acids. The 1,2-dienol common to mannose, glucose, and levulose,



as well as the 1,2-dienol common to *d*-talose, *d*-galactose, and

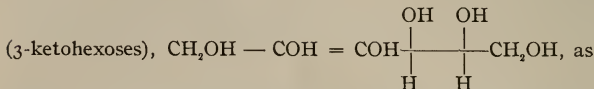


to any appreciable extent into oxymethylene and the pentose, *d*-arabinose or *d*-lyxose, respectively, since it has not been possible in any case up to the present time to show that any pentonic acid is formed by the action of Fehling's solution on hexoses. The formation of 2,3-dienols, as well as of 3,4-dienols, from the hexoses and their subsequent splitting is a necessary prelude to the formation of the

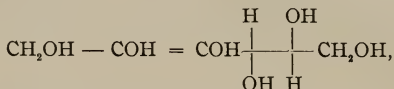
¹ See especially *Ann. Chem. (Liebig)*, **357**, 294-312.

monobasic acids containing from one to four carbon atoms, as well as of the new hexonic acids, α -oxymethyl-*d*-arabonic and α -oxymethyl-*d*-lyxonic acids, mentioned above.

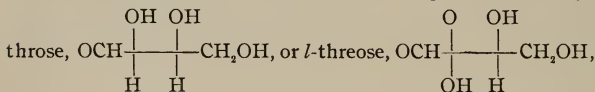
The 2,3-dienol which is common to *d*-fructose and *d*-pseudo-fructose (2-ketohexoses), and also to α - and β -*d*-glucose



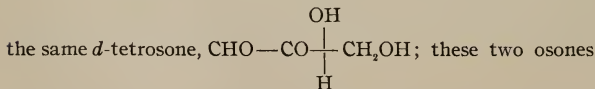
well as the 2,3-dienol common to *d*-tagatose and *l*-sorbose (2-ketohexoses), and to α - and β -*d*-galactose (3-ketohexoses),



then simply breaks, by methylene dissociation, in a manner entirely analogous to the double cyanides, $\text{KN} : \text{C} = \text{C} : \text{NAg}$, $\text{RN} : \text{C} = \text{C} : \text{NAg}$, etc.,¹ into diose, CH_2OHCHO , *d*-ery-



respectively. Diase then gives, by oxidation with Fehling's solution, glyoxal, whereas the two tetroses must give one and

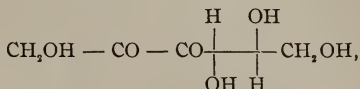
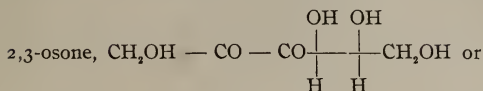


then give, by a benzilic acid rearrangement, glycollic acid, on the one hand, and two trioxybutyric acids, namely, *l*-threonic and *d*-erythronic acids, on the other. Obviously some of the diase thus formed dissociates further, through formation of the dienol, $\text{CHOH} = \text{CHOH}$, into two molecules of oxymethylene, $=\text{CHOH}$, which, of course, then gives formic acid by further oxidation.

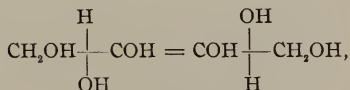
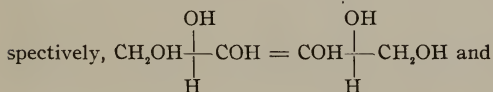
The 3-ketohexoses, α - and β -*d*-glucose and α - and β -*d*-galactose, which are formed by the action of alkalis on the corre-

¹ Nef: Ann. Chem. (Liebig), **298**, 215, 313; and THIS JOURNAL, **30**, 466, footnote.

sponding aldohexoses, give, as has been sharply proved by Spoehr's work, through an intermediate formation of the



and subsequent *entire* asymmetric benzilic acid rearrangement, only α -oxymethyl-*d*-arabonic or α -oxymethyl-*d*-lyxonic acid, respectively. The 3-ketohexoses finally are the intermediate products which are the source of all the *d*- and *l*-glycerinic acid formed by the action of Fehling's solution on all aldohexoses. The 3,4-dienols which are common to α -*d*-glucose and α -*d*-galactose and to β -*d*-glucose and β -*d*-galactose, re-



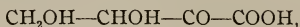
must in all cases, as soon as formed, spontaneously dissociate into two molecules of *d*- or *l*-glyceric aldehyde; these products then give, by oxidation, mainly glycerosone,



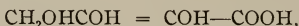
which, by a benzilic acid rearrangement, gives equal amounts of *d*- and *l*-glycerinic acid. The members of the *d*-glucose series give relatively far more glycerinic acid than those of the *d*-galactose series for exactly the same reason that the *d*-glucose series gives relatively more *d,l*-lactic acid, as compared with the *d*-galactose series, when treated with caustic alkalies—namely, because there is more formation of 3,4-dienol, and

consequent spontaneous dissociation into two molecules of triose, in the former than in the latter case.¹

Finally, the formation of small amounts of carbonic and oxalic acids from hexoses by the action of alkaline cupric hydroxide is best explained on the assumption that the various osones oxidize partially to α -keto acids,² which then lose carbon dioxide, giving a lower homologous sugar and in part, also, through enol formation and subsequent dissociation, give glyoxylic acid, etc.; thus tetrosone, for example, could give, by oxidation of the aldehyde group, the α -keto acid,



which, as dienol,



must automatically dissociate into diose and glyoxylic acid.³

EXPERIMENTAL PART.

A solution of 382.5 grams copper vitriol in two liters of water was mixed in the cold, as directed by Nef,⁴ with a solution of 183.9⁵ grams of sodium hydroxide in 688 cc. of water, *i. e.*, with 61.3 grams more sodium hydroxide than the amount necessary for the formation of cupric hydroxide. Then a solution of 59 grams of *d*-galactose melting at 152°–154°, the exact amount necessary as determined by previous tests, in 250 cc. water was added. The mixture was placed at once in a large

¹ Nef: Ann. Chem. (Liebig), **357**, 300.

² Cf. Nef: *Ibid.*, **357**, 258.

³ An entirely analogous interpretation holds for the products formed by the action of Fehling's solution on aldopentoses; since my experiments (soon to be published) prove that the tetroses, through intermediate formation of 2,3-dienols, dissociate mainly into two molecules of diose, it follows that the large amount of glycollic acid observed by Mr. Anderson in his work on *d*-galactose comes mainly through a splitting of this sugar, in two steps, into three molecules of glycollic aldehyde. Finally, I would like to emphasize here that all sugars containing from two to six carbon atoms in the molecule, when treated in alkaline solution with air, give exactly the same products and in relatively the same amounts as when cupric hydroxide is present (*i. e.*, as with Fehling's solution). It is therefore my intention not to repeat the work with Fehling's solution, but to determine with students, by sharper quantitative methods, the nature of all the products formed by treating various sugars in alkaline solution with a rapid stream of air.—J. U. NEF.

⁴ Ann. Chem. (Liebig), **357**, 217.

⁵ The weight given is corrected to 100 per cent. sodium hydroxide. I used 191.2 grams sodium hydroxide, 96.2 per cent. pure.

bath of boiling water and heated for two hours, with frequent shaking. Cuprous oxide appeared two minutes after mixing the solutions, when the inside temperature was only 30° . The reaction was complete in twelve minutes, when a temperature of 60° had been reached. As soon as the cuprous oxide had settled, the clear, slightly yellow solution was filtered hot; the cuprous oxide was washed by decantation four times and finally on the filter with hot water. These operations were repeated with a second portion of 59 grams *d*-galactose and the combined aqueous filtrates were then worked up for nonvolatile acids. The amount of carbon dioxide and of formic acid formed in the oxidation was determined in special experiments as given below.

Determination of Carbon Dioxide.—An aqueous filtrate, obtained as described above, from 58 grams of *d*-galactose, etc., was diluted to five liters with water and the amount of carbon dioxide in one liter was then determined quantitatively as directed by Nef.¹ This gave 1.51 grams of barium carbonate from one liter, or a total of 7.55 grams of barium carbonate from the five liters. In a special determination, 25 grams of the sodium hydroxide used gave 0.28 gram of barium carbonate; 187.6 grams of sodium hydroxide, *i. e.*, the amount used with the 58 grams *d*-galactose, would therefore give 2.10 grams of barium carbonate. Correcting for this amount of barium carbonate, 58 grams of the sugar gave 1.22 grams carbon dioxide; hence 100 grams *d*-galactose give 2.11 grams of carbon dioxide.

Determination of Formic Acid.—In order to set free the volatile, as well as the nonvolatile acids, an aqueous filtrate obtained from 58 grams *d*-galactose, as directed above, was treated with exactly the calculated amount of hydrogen chloride, *i. e.*, with the amount necessary to neutralize one-third of the total amount of sodium hydroxide originally used; water and formic acid were then distilled off under 15–30 mm. pressure, finally on the boiling water bath. The distillate was diluted to four liters with water and the formic acid determined by titration with 0.1 N potassium hydrox-

¹ Ann. Chem. (Liebig), **357**, 219.

ide, phenolphthalein being used as the indicator; 250 cc. of the distillate required 107.8 cc. of 0.0974 N potassium hydroxide. The total amount of formic acid given by 58 g ams *d*-galactose is therefore 7.73 grams and by 100 grams *d*-galactose is 13.3 grams.

Separation of the Nonvolatile Acids.—The nonvolatile acids left with the salt residue after treating the aqueous filtrates obtained from two portions of 59 grams *d*-galactose with the calculated amount of hydrogen chloride and removing the volatile acids as stated above, were now worked up as follows. Extraction with two liters of hot 95 per cent. alcohol gave a total of 121 grams gum, which was freed from inorganic salts and resolved into three fractions. First it was digested with four liters of ethyl acetate, which took up 87.5 grams gum. The insoluble portion left, on digesting with 1500 cc. absolute alcohol, 18.9 grams inorganic salts, and the filtrate gave, on removal of the solvent in the usual manner (at 100° and 15–30 mm.), 14.6 grams least soluble gum C. The 87.5 grams gum soluble in acetic ether was now resolved, by dissolving in 50 cc. absolute alcohol and subsequent addition of 500 cc. ether, into 33.8 grams soluble gum A, and 53.7 grams of precipitated gum B. Fraction A contains the glycollic acid mainly; fraction B consists of glycerinic and trioxybutyric acids mainly, but contains also some hexonic acids; while fraction C is mainly a mixture of *d*-galactonic and talonic acids; there also appear in the course of the various subsequent operations, especially on treating fractions B and C with quinine, varying amounts of a gum which is difficultly soluble in spirit and practically insoluble in absolute alcohol and which seems to be analogous to Nef's so-called polygluconic acid;¹ the nature of this neutral product, which I call polygalactonic lactone, could not be determined, but it is certainly not a primary reaction product and its formation could at times be entirely avoided.

There are two methods by which the components of fractions A, B and C can be separated: *d*-talonic and *d*-galactonic acids may in great part be removed from fractions B and C by direct treatment in the cold with equal volumes of alcohol and phenyl-

¹ Ann. Chem. (Liebig), **357**, 268, 276, 281.

hydrazine.¹ Since, however, these two acids give low-melting (110° – 130°) brucine salts which can be partly, but not sharply, separated, by crystallization from alcohol, from the high-melting brucine salts formed by *d*- and *l*-glycerinic, as well as by all the four isomeric trioxybutyric acids, I preferred to accomplish first a partial separation of the various acids by fractional crystallization of the brucine salts into low- (90° – 110°) and high- (190° – 210°) melting salts and then to treat only the acids giving low-melting brucine salts with phenylhydrazine; the *d*-galactonic and *d*-talonic acid phenylhydrazides, which separate out, could then be sharply separated by boiling out with much absolute alcohol in which the former is practically insoluble.

The separation of the monobasic acids containing three and four carbon atoms in the molecule, all giving high-melting (205° – 220°) brucine salts which are difficultly soluble in absolute alcohol, was found exceedingly difficult: *d,l*-glycerinic brucine, as has been shown by Neuberg,² can be separated into its components by crystallization from alcohol (*but not sharply, as I have found*) since *d*-glycerinic brucine, $[\alpha]_D^{20} = -33^{\circ}.2$, is far less soluble. Preliminary unpublished experiments by Nef, which I have confirmed, show that *d,l*-glycerinic quinine can be very completely separated into its optical components, since *l*-glycerinic quinine is very difficultly soluble in cold water, whereas *d*-glycerinic quinine is very soluble.

Nevertheless, I finally succeeded in proving very sharply that the acids giving high-melting brucine salts consisted mainly of equal amounts of *d*- and *l*-glycerinic acid, and that only a small amount of *l*-threonic and still less *d*-erythronic acid was present. The *l*-threonic acid separated out in great part as a difficultly soluble phenylhydrazide on treatment of the gum obtained from the least soluble high-melting brucine salts with phenylhydrazine and alcohol. The presence of very small amounts of *d*-erythronic acid, on the other hand, could be established only by oxidation to mesotartaric acid.

¹ Cf. Nef: Ann. Chem. (Liebig), **357**, 261.

² Ber. d. chem. Ges., **37**, 340.

Glycollic Acid, Gum A.—On digesting gum A, 33.8 grams, on the boiling water bath for 9 hours with water and an excess of pulverized strychnine, 106 grams of the alkaloid dissolved. The strychnine salts, after distilling off the water under 15–30 mm. pressure, gave, on dissolving in alcohol and letting stand, a total of 69.9 grams of crude glycollic strychnine, melting from 160° to 200° ; from this, on digestion for 10 hours on a boiling water bath with water and an excess of powdered quicklime, subsequent filtration, concentration, etc., 20.1 grams of crystalline calcium glycolate were finally obtained, corresponding to 11.75 grams anhydrous glycollic acid.

0.9608 gram air-dried salt lost, on drying at 100° – 120° , 0.2716 gram H_2O .

0.6892 gram anhydrous salt, on ignition, gave 0.2016 gram CaO .

Calculated for $Ca(C_2H_3O_2)_2 \cdot 4H_2O$.		Found.
H_2O	27.48	28.23
CaO	29.47	29.25

The 69.9 grams gummy strychnine salts which were left in the alcoholic filtrates gave back, on treating with an excess of aqueous sodium hydroxide, filtering off the alkaloid, adding the calculated amount of hydrochloric acid, removing the water by distillation under a pressure of 15–30 mm. and, finally, extracting the salt residue with acetic ether, a total of 18.6 grams of acid gum, mainly glycerinic and trioxybutyric acids, all of which give high-melting (200° – 220°) brucine salts, which crystallize beautifully from absolute alcohol. The gum was therefore diluted with water to 500 cc.; 10 cc. of this solution, corresponding to 0.372 gram gum, required 33.22 cc. 0.1 N potassium hydroxide for neutralization, *i. e.*, by heating for ten minutes on the boiling water bath with a decided excess of 0.1 N potassium hydroxide, the excess of alkali being then titrated with 0.1 N hydrochloric acid and phenolphthalein as indicator.¹ The main

¹ This method has subsequently been found to give too high (about 10 per cent.) results, so that some free brucine was invariably present on treating the main portion of my acid gums with the calculated amount of alkaloid.

portion of the acid gum in water was now converted into brucine salts in the usual way, *i. e.*, by adding a small volume of alcohol and the amount of brucine calculated¹ on the basis of the titration, 64.13 grams, digesting on the boiling water bath for one hour after complete solution of the alkaloid and then distilling off the water under a pressure of 15–30 mm., heating finally to 80°. On dissolving the salts thus obtained in an equal weight of absolute alcohol a total of 37.5 grams, in four portions, of crystalline high-melting (208°–210°) salts were obtained. The gummy brucine salts, weighing 42 grams and containing some free brucine, gave back, on treating in aqueous solution with sodium hydroxide, filtering off the brucine, extracting the alkaline solution with chloroform, adding the calculated amount of hydrochloric acid, and finally distilling off the water under 15–30 mm. pressure and extracting the salt residue with absolute alcohol, a total of 8.5 grams acid gum, which was united with 10.2 grams of analogous gum obtained from fraction B.

Fraction B, 53.7 Grams.—Gum B was diluted with water to one liter; 10 cc. of this solution, containing 0.537 gram, required 43.28 cc. 0.1 N potassium hydroxide for neutralization.¹ The main portion of the solution, on treatment with the calculated amount, 168.9 grams, brucine gave 255 grams crude brucine salts still containing some water. These were separated by crystallization from alcohol into four fractions: 57.7 grams salts melting from 90° to 110°; 61.3 grams melting from 90°–100°; 33.2 grams melting from 206°–208; and finally 60 grams gummy salts. The nature of the first three crystalline fractions will be discussed in detail later. The 60 grams noncrystalline salts gave, on conversion to the free acids in the usual way, 10.2 grams acid gum, soluble in absolute alcohol, which was united with 8.5 grams of gum recovered from fraction A. This was now resolved, by dissolving in 20 cc. absolute alcohol and adding 350 cc. of ether, into 11 grams of soluble gum and 7 grams of precipitated gum; the latter was united with 9 grams of difficultly soluble gum obtained from fraction C (see below). The 11 grams of

¹ See footnote, p. 410.

soluble gum, on the other hand, yielded no more strychnine glycollate on conversion into strychnine salts, and gave back 10.1 grams of gum soluble in absolute alcohol, and this, after titration of 0.2 gram, which required¹ 19 cc. 0.1 N potassium hydroxide, was converted in the usual manner into brucine salts. Crystallization of these from alcohol gave a total of 27.1 grams, in three crops, of crystalline salts melting from 90° to 110°, besides 20 grams noncrystalline salts which were united with a corresponding fraction from gum D (see below).

Fraction C, 14.6 Grams.—Gum C was diluted with water to 250 cc.; 5 cc. of this solution, containing 0.292 gram of gum, required 22.2 cc. 0.1 N potassium hydroxide for neutralization.² The main portion gave, on treatment with 42.86 grams of brucine, 64 grams crude brucine salts which, on crystallization from alcohol, gave only 11.1 grams of crystalline salts melting from 90° to 110°. The remainder, about 50 grams gummy salt, gave back with sodium hydroxide, etc., 9 grams of gum soluble in 95 per cent. alcohol, but not entirely in absolute alcohol, and containing, therefore, some polygalactonic lactone; this was now united with a corresponding 7 grams gum from fraction B (see above). The combined gums gave, on heating for 9 hours from 80° to 100° with 48 cc. acetic anhydride,³ etc., besides 6.5 grams of insoluble gum, tar, and sodium chloride, 16.2 grams acylated gum, soluble in hot ether, which, on fourfold hydrolysis with three parts of water, gave back 10.6 grams gum. This, on dissolving in 20 cc. absolute alcohol and adding 40 cc. ether, was separated into 6.75 grams soluble gum (D), and 3.7 grams precipitated gum (E); the former, after titration of 0.27 gram, which required 24.22 cc. 0.1 N potassium hydroxide, was treated with the calculated⁴ amount, 22.9 grams, of brucine. On dissolving the salts in alcohol a total of 10.4 grams high-melting (190°–204°) crystalline brucine salts were obtained.

¹ See footnote, p. 410.

² *Ibid.*, p. 410.

³ Cf. Nef: *Ann. Chem. (Liebig)*, **357**, 239–40.

⁴ See footnote, p. 410.

Since experience with *d,l*-glycerinic brucine has shown that this salt is partially resolved by crystallization from alcohol into its optical components, the *d* modification, $[\alpha]_D^{20} = -33^\circ.2$, being far less soluble in alcohol whereas the *l* modification, $[\alpha]_D^{20} = -22^\circ$, is decidedly more soluble and often comes out very slowly from alcohol, it was thought probable that the various gummy brucine salts mentioned above might still contain appreciable quantities of *l*-glycerinic brucine; this could easily be ascertained by conversion of the acids into the quinine salts in which the presence of *l*-glycerinic quinine melting at 184° , which is very difficultly soluble in cold water, could then easily be recognized. The alcoholic mother liquors from the 10.4 grams high-melting brucine salts mentioned above were therefore united with 20 grams of analogous gummy brucine salts obtained from fraction B, and in all 7.3 grams acid gums were recovered from these by sodium hydroxide, etc. These gums took up 17.3 grams quinine on digestion for 8 hours in aqueous solution on a boiling water bath, but on crystallizing the salts obtained from water, only 6.6 grams of quinine salts, melting from 120° to 130° on repeated crystallization, and therefore probably consisting of impure *l*-glycerinic quinine, were obtained. The aqueous filtrate, still containing about 13.2 grams salts, was found to contain a small amount of neutral polygalactonic lactone, which was removed by dissolving in absolute alcohol; the remainder gave back, with sodium hydroxide, etc., 3 grams of acid gum (F).

On treating gum E, 3.7 grams, after titration of 0.296 gram, which required 18.3 cc. 0.1 N potassium hydroxide, with the calculated amount, 8.3 grams, of brucine, no crystalline salts were obtained and the recovered acid gums, 3.5 grams, gave, on treatment with 3.5 cc. each of alcohol and phenylhydrazine, after standing 24 hours in the cold, 0.4 gram *d*-galactonic phenylhydrazide, melting from 195° to 200° . The gummy hydroxides, soluble in alcohol, on being hydrolyzed as directed by Nef,¹ gave back 2.8 grams of acid gum; this, on long digestion in aqueous solution with quinine, took up

¹ Ann. Chem. (Liebig); 357, 228.

5.1 grams of alkaloid. On crystallization of the salts obtained from water, only 0.2 gram of a crystalline salt, melting at 160° , which was probably *l*-glycerinic quinine, was obtained. The filtrate was found to contain some polygalactonic lactone and finally gave back, with sodium hydroxide, etc., 1.2 grams of acid gum, which will be referred to later on.

Summary.

The resolution of the 102.1 grams nonvolatile acid gums from 118 grams *d*-galactose, which has been described in some detail on the preceding pages, may be briefly summarized as follows: I. A total of 157.2 grams low-melting (90° – 110°) brucine salts were obtained in four fractions of 57.7, 61.3, 27.1 and 11.1 grams; these consist, as will be shown later in this paper, largely of *d*-galactonic and *d*-talonic brucine, but a fair amount of glycerinic and trioxybutyric brucine salts is also present. II. 81.1 grams high-melting (190° – 210°) brucine salts of *d*- and *l*-glycerinic, *l*-threonic and *d*-erythronic acids in three fractions of 37.5, 10.4 and 33.2 grams. III. 20.1 grams crystallized calcium glycollate. In addition, 3.0 grams gum (F) and 1.2 grams gum (from E) have not been identified in the form of crystalline derivatives; finally, a fair amount of neutral polygalactonic lactone gum was obtained in the course of the various operations employed, besides 0.4 gram crystallized *d*-galactonic phenylhydrazide and 6.6 grams crude *l*-glycerinic quinine melting from 120° to 130° .

I. d-Galactonic and d-Talonic Acid from the Low-melting Brucine Salts.—The two acids just named can be separated, as Fischer¹ has shown, by means of the cadmium salts. They can also be separated by means of the hydrazides and I have used the latter method exclusively in my work. Fraction I., 57.7 grams brucine salts obtained from oil B and melting from 90° to 110° , gave, when treated with sodium hydroxide, etc., 17.5 grams of acid gum; this, on treatment with 17.5 cc. alcohol and 17.5 cc. phenylhydrazine gave, after standing 24 hours, 15.7 grams insoluble crystalline hydrazides melting at 185° after being well washed with cold alcohol; the results

¹ Ber. d. chem. Ges., 24, 3623.

obtained with the alcoholic filtrate are described further on. On crystallizing the insoluble hydrazides from about 30 cc. hot water, 13.1 grams of practically pure *d*-galactonic phenylhydrazide, melting from 200° to 205° , were obtained; the aqueous filtrate distilled off at reduced pressure gave 2.6 grams *d*-galactonic phenylhydrazide melting from 150° to 155° . The *d*-galactonic phenylhydrazide finally was recrystallized once more before analysis by dissolving in five parts of hot water, filtering and adding about twenty parts of absolute alcohol; it separates out in colorless leaflets pointed at one end and melting from 203° to 205° .

0.1942 gram, dried *in vacuo*, gave 0.3596 gram CO_2 and 0.1212 gram H_2O .

0.1984 gram, dried *in vacuo*, gave 17.20 cc. N at 18° .5 and 744.6 mm.

	Calculated for $\text{C}_{12}\text{H}_{18}\text{O}_6\text{N}_2$.	Found.
C	50.35	50.51
H	6.29	6.99
N	9.79	9.86

An optical determination gave: $d = 1.005$; $p = 2.201$; *i. e.*, 0.5609 gram substance and 24.9228 grams water; $[\alpha]$ in a 1 dcm. tube = $+0^{\circ}.231$, whence $[\alpha]_D^{20} = +10^{\circ}.44$.

For comparison, I also made *d*-galactonic acid from *d*-galactose by oxidation with bromine, using in general the method of Kiliani.¹ Three grams of the acid, obtained from the crystallized calcium salt, gave, on treatment with phenylhydrazine and alcohol in the cold, 3.9 grams of crystals melting from 190° to 200° ; these, when recrystallized from water and alcohol as mentioned above, gave leaflets, pointed at one end, melting from 203° to 205° . An optical determination gave: $d = 1.005$; $p = 2.051$; *i. e.*, 1.0434 grams of substance and 49.8356 grams of water; $[\alpha]$ in a 2 dcm. tube = $+0^{\circ}.447$, whence $[\alpha]_D^{20} = +10^{\circ}.84$.

The 2.6 grams of crude *d*-galactonic phenylhydrazide mentioned above was recrystallized from fifty parts of hot absolute alcohol and gave, on cooling, a large amount of crystals melting between 161° and 162° .

¹ Ber. d. chem. Ges., 18, 1552.

0.1929 gram, dried *in vacuo*, gave 0.3550 gram CO_2 and 0.1146 gram H_2O .

0.2004 gram, dried *in vacuo*, gave 17.32 cc. N at 17° and 734.5 mm.

	Calculated for $\text{C}_{12}\text{H}_{18}\text{O}_6\text{N}_2$.	Found.
C	50.35	50.19
H	6.29	6.66
N	9.79	9.77

An optical determination gave: $d = 1.011$; $p = 3.995$; *i. e.*, 0.5600 gram substance and 13.4572 grams of water; $[\alpha]$ in a 1 dcm. tube = $-1^\circ.00$, whence $[\alpha]_D^{20} = -24^\circ.75$.

Finally, *d*-galactonic acid, by treatment with pyridine and water, as directed by Fischer,¹ was converted into a mixture of *d*-galactonic and *d*-talonic acids. This mixture, on treatment with phenylhydrazine, etc., gave a large amount of *d*-galactonic hydrazide melting from 190° to 200° , and a smaller amount of crude *d*-talonic hydrazide melting between 150° and 155° . The latter, after two crystallizations from fifty parts hot absolute alcohol, gave a pure product melting between 161° and 162° ; the optical investigation gave: $d = 1.011$; $p = 3.6525$; *i. e.*, 0.4462 gram substance and 11.7700 grams water; $[\alpha]$ in a 1 dcm. tube = $0^\circ.92$; whence $[\alpha]_D^{20} = -24^\circ.91$. Fischer gives the melting point 155° for *d*-talonic phenylhydrazide; the product was probably not absolutely pure, since I have observed that when my synthetic *d*-talonic phenylhydrazide melted at 155° it gave $[\alpha]_D^{20} = -22^\circ.84$ in 4 per cent. concentration, but on further recrystallization the melting point invariably rose to 161° – 162° and the specific rotation to the value just given. From the data given it is evident that the product obtained by me from *d*-galactose and Fehling's solution was *d*-talonic phenylhydrazide.

The above mentioned alcoholic filtrate from the 15.7 grams crude mixture of *d*-galactonic and *d*-talonic phenylhydrazides, which contained the alcohol-soluble hydrazides, gave back, after hydrolysis according to the method of Nef,² 8.5 grams of acid gum; 0.33 gram of this required 21.5 cc.

¹ Ber. d. chem. Ges., **24**, 3623.

² *Loc. cit.*

of 0.1 N potassium hydroxide for neutralization. The remainder was therefore treated with the calculated amount, 20.32 grams, of brucine. The brucine salts gave, on crystallization from 90 per cent. alcohol, 4.4 grams, crop I, melting at 156° , and shown later to be pure *d*-talonc brucine, and 8.26 grams, crop II, melting from 130° to 138° . The latter, on treatment with sodium hydroxide, etc., gave 2 grams of gum which, mixed in the usual manner with phenylhydrazine and alcohol, gave only 0.85 gram crystalline hydrazide melting from 180° to 185° , which was resolved by digestion with hot alcohol into 0.6 gram *d*-galactonic phenylhydrazide melting at 198° – 200° , and 0.25 gram crude *d*-talonc phenylhydrazide melting 150° – 155° . The alcoholic filtrates containing the soluble gummy hydrazides, including a small amount from fraction II, described below, gave back, on hydrolysis, 2.0 grams of acid gum which was united with the 3.0 grams of gum F, mentioned above, and treated with 10 grams of brucine; the salts obtained gave, on crystallization from alcohol, 2.45 grams crystalline salt melting at 150° , which is shown below to be practically pure *d*-talonc brucine. The alcoholic filtrate gave back 3.4 grams acid gum which gave no further crystalline hydrazides on treatment with phenylhydrazine and alcohol; the gummy hydrazides were therefore united with a corresponding fraction referred to below, which was obtained from 27.1 grams low-melting salts from fraction D.

Fraction II, low-melting brucine salts, 61.3 grams obtained from B as well as 11.1 grams of a corresponding salt from C, gave, on treatment with sodium hydroxide, etc., 18.6 grams of gum; this gave, on treatment with 19 cc. each of alcohol and phenylhydrazine, noticeably less insoluble crystalline hydrazides, 5.7 grams, than was the case with crop I, just described. Furthermore, the mixture was resolved by crystallization from hot water into 5 grams *d*-galactonic hydrazide melting at 200° and 0.7 gram insoluble oxalyl hydrazide melting from 230° to 260° . Oxalyl hydrazide, which was also made for comparison from oxalic acid and phenylhydrazine by mixing in alcoholic solutions, is very difficultly solu-

ble even in boiling water or alcohol; it can be recrystallized from 5 per cent. sodium carbonate solution as directed by Bülow,¹ but is partly decomposed by the operation. On digesting the 0.7 gram mentioned above with 800 cc. hot alcohol only a portion dissolved and, on standing, yellowish, very thin leaflets, melting from 230° to 260°, separated out.

The original alcoholic filtrate containing all the gummy hydrazides from fraction II, except a small amount that was mentioned under fraction I, gave back, on hydrolysis, 15 grams of gum; 0.3 gram of this required 21.4 cc. 0.1 N potassium hydroxide for neutralization. The remainder was accordingly heated with 41.3 grams brucine and on crystallizing the salts obtained, first from ethyl alcohol and finally from methyl alcohol, a total of 32.35 grams, in three crops, of crystalline brucine salts melting from 90° to 115° were obtained (see p. 419); the noncrystalline brucine salts gave back, with sodium hydroxide, etc., 10.5 grams of acid gums which, on digesting 10 hours with an excess of quinine and water, took up 20 grams of this alkaloid. On crystallizing the salts obtained from a small amount of water, only 0.55 gram crystalline substance, melting at 160° (which was later worked up for *l*-glycerinic acid), separated out. The aqueous filtrate, after removing some polygalactonic lactone by dissolving in absolute alcohol, etc., gave back with sodium hydroxide 7 grams unidentified gum, from which, on further treatment with brucine, no crystalline salts could be obtained (see below).

Finally, the 27.1 grams low-melting brucine salts obtained from fraction D gave, with sodium hydroxide, 6 grams of gum which, when digested for 10 hours with water and quinine, took up 11 grams of the alkaloid, but no crystalline salts could be obtained by dissolving in water or alcohol. After removing some polygalactonic lactone in the usual manner, 4 grams of acid gum was recovered. This was converted into salts by digesting with 8.8 grams of brucine, but on crystallization from methyl alcohol only 1.22 grams of *d*-talonic brucine salt, melting at 150°, was obtained. The gummy

¹ Ber. d. chem. Ges., 35, 3688.

brucine salts, decomposed with sodium hydroxide, etc., gave back 3.4 grams of gum which, on treatment with phenylhydrazine and alcohol, gave 0.6 gram *d*-galactonic hydrazide, melting from 195° to 198°. The noncrystalline soluble hydrazides were now combined with a similar mixture obtained from gum F, above, and gave, on hydrolysis, 5.2 grams unidentified gum (see below).

d-Talonie Brucine.—Three fractions of *d*-talonie brucine are referred to in the preceding pages, namely: 1.22 grams, melting at 150°; 2.45 grams melting at 150°; and 4.4 grams melting at 156°. These were obtained from gummy hydrazides soluble in alcohol and show very clearly that *d*-talonie acid, when treated with phenylhydrazine and alcohol (even when alone, as proved by an experiment with a synthetic product), is never precipitated completely as the phenylhydrazide. Fischer gives the melting point of *d*-talonie brucine at 130°–133°. I have found that this salt, when crystallized from its weight of water mixed with six times its weight of absolute alcohol, has, when air-dry, the melting point given by this investigator, but that on drying *in vacuo* it loses about 10 per cent. in weight and the melting point then goes up to 154°–156°. The combined three fractions of *d*-talonie brucine just mentioned, 8.07 grams, gave with sodium hydroxide, etc., 2.1 grams of acid gum which, mixed with 2.1 cc. each of alcohol and phenylhydrazine, gave 2.4 grams crude *d*-talonie phenylhydrazide well washed with cold alcohol; since a preparation of pure synthetic *d*-talonie acid gum was found to give only 75 per cent. of the theoretical amount of hydrazide on similar treatment, it is obvious that practically pure *d*-talonie acid was present.

The 32.35 grams of brucine salts, in three crops, melting between 90° and 115°, referred to on p. 418, gave, with sodium hydroxide, etc., 7.6 grams of gum which, on digestion with an excess of quinine and water for 10 hours, took up 13.1 grams of alkaloid. No crystalline salts could be obtained, and after the removal of some polygalactonic lactone, the quinine was split off with sodium hydroxide and 5.5 grams of acid gum recovered. This, on treatment with 12 grams of brucine and

crystallization of the resulting salts from alcohol, gave 8.9 grams of brucine salts melting at 138° ; the remaining gummy brucine salts, decomposed with sodium hydroxide, etc., gave 2 grams of gum which, with phenylhydrazine and alcohol, gave 0.3 gram *d*-galactonic hydrazide melting at 195° . The 8.9 grams of crystalline salts gave back 2 grams of gum which, on similar treatment, gave 1.0 gram of *d*-talonic hydrazide, melting between 150° and 160° . The gummy soluble hydrazides from these two fractions gave back, on hydrolysis, 3 grams of unidentified gum (see below).

Unidentified Acid Gums from the Low-melting Brucine Salts.—The total amount of unidentified acid gums obtained finally from the various gummy brucine and quinine salts, as well as from gummy hydrazides, in the operations with the 157 grams of low-melting brucine salts described in the preceding pages, was 18.5 grams. These were now separated into 10.5 grams, I, soluble in acetic ether, and 8 grams, II, soluble in absolute alcohol. The amount of glycerinic acid present in I was now determined as directed by Nef;¹ 0.45 gram gave, with concentrated hydriodic acid, etc., 0.18 gram β -iodpropionic acid melting from 81° to 83° ; hence about 40 per cent. of this material consists of glycerinic acid. This was also confirmed by taking 9.0 grams of the gum, I, and treating it, on the basis of a titration, with 32.2 grams brucine, etc.; on crystallizing the salts from alcohol, 19 grams melting from 190° to 205° , besides 2.22 grams melting from 120° to 130° , were obtained. The presence of *d*-erythronic acid in traces in this 19 gram portion of high-melting salts was subsequently established by experiment (see below). The 2.22 grams low-melting salt, decomposed with sodium hydroxide, gave 0.6 gram gum which, treated with phenylhydrazine and alcohol, gave 0.4 gram *d*-talonic hydrazide melting at 153° – 156° . Finally, the alcoholic filtrate containing the gummy brucine salts gave back with sodium hydroxide, etc., 4.2 grams of acid gum which was united with gum II, 8 grams, after freeing the latter from tar as follows: Acylation for 8 hours at 100° with three parts of acetic anhy-

¹ Ann. Chem. (Liebig), **357**, 263.

drude gave only a relatively small amount of acylated gum soluble in hot ether which, on threefold hydrolysis, gave 3.25 grams of gum. The total amount of unidentified gum was therefore now 7.45 grams which, by means of hot acetic ether, was separated into 3.4 grams, soluble in this solvent, and 3.25 grams insoluble gum. The former, treated with 11.3 grams of brucine, etc., gave 2.63 grams of crystalline brucine salts melting at 202° . But no further crystalline salts could be obtained from either fraction; they were, therefore, finally discarded. The 2.63 grams high-melting brucine salt was not worked up further. It is evidently the same in character as the 19 gram portion mentioned above, which was subsequently proved to contain small amounts of *d*-erythronic acid.

II. 1-Threonic, d-Erythronic, d,l-Glycerinic Acids from the High-melting Brucine Salts.—A preliminary attempt to separate the 70.75 grams, in two crops of 37.5 grams and 33.2 grams, respectively, from fractions A and B, of brucine salts melting between 206° and 208° soon showed that *d,l*-glycerinic acid was being split into its components, as described by Neuberg.¹ I repeated part of his work and obtained, in general, similar results. But on the whole I have found brucine less satisfactory than quinine, as used by Nef, in separating *d,l*-glycerinic acid into its components.

On the Resolution of d,l-Glycerinic Acid into Its Optical Components.—Ten grams of *d,l*-glycerinic acid gum (made from Kahlbaum's calcium glycerinate after crystallizing twice from water) was digested for 10 hours on the boiling water bath with water and 34.35 grams of quinine; complete solution took place and on concentrating to about 100 cc. a mass of crystalline needles separated out after standing 12 hours. These, when filtered, washed with 50 cc. water and dried on a porous plate, weighed 22.05 grams and melted at 178° . On recrystallization from 40 cc. hot water, 14.7 grams of the anhydrous salt, melting at 183° , was obtained. Ten grams of this, decomposed with sodium hydroxide, etc., gave 2 grams of acid gum. On digesting the gum with 300 cc. acetic ether,

¹ Ber. d. chem. Ges., **37**, 340.

1.65 grams dissolved. I have always found that a portion of the glycerinic acid gum remains insoluble but that the greater part is very easily soluble in this solvent. The soluble portion was now converted into the calcium salt which, on concentration of its solution to 10 cc. and subsequent addition of 10 cc. alcohol, gave 0.55 gram of salt melting at 138° and having a specific rotation of only $+3^{\circ}.70$ for the hydrated salt, which corresponds to $+4^{\circ}.08$ for the anhydrous salt. The mother liquor, however, on concentration to 4 cc. and addition of 8 cc. alcohol, gave a second crop of practically pure *l*-glycerinic calcium, 1.2 grams, melting at 138° , and giving $[\alpha]_D^{20} = +14^{\circ}.07^1$ for the hydrated salt, which corresponds to $[\alpha]_D^{20} = +15^{\circ}.53$ for the anhydrous salt: $d = 1.011$; $p = 4.01$, *i. e.*, 0.8038 gram substance dried *in vacuo* and 19.2586 grams of water; $[\alpha]$ in a 1 dcm. tube = $+0^{\circ}.57$.

l-Glycerinic Brucine.²—The 1.1 grams of *l*-glycerinic calcium, $[\alpha]_D^{20} = +14^{\circ}.07$, mentioned above, was converted in the usual manner into 0.75 gram *l*-glycerinic acid gum, which, treated with 2.78 grams of brucine, etc., gave, from 63 cc. absolute alcohol, 2.35 grams of pure anhydrous *l*-glycerinic brucine in heavy transparent crystals, melting at 222° ; the specific rotation at 20° was found to be $-22^{\circ}.02$; $d = 1.011$; $p = 3.962$, *i. e.*, 0.7710 gram substance dried *in vacuo* and 18.6886 grams of water; found $[\alpha]$ in a 1 dcm. tube = $-0^{\circ}.882$.

d-Glycerinic Quinine.—The aqueous filtrate from the 22.05

¹ Cf. Frankland: J. Chem. Soc., **63**, 297; also Fischer: Ber. d. chem. Ges., **40**, 1069–1070. The highest rotation given by Fischer for hydrated glycerinic calcium is $+14^{\circ}.5$ in 4.6 per cent. concentration.

² The absolute space formula of *l*-glycerinic acid has been determined by Neuberg

(Z. physiol. Chem., **44**, 145) as being $\text{COOH} \begin{array}{c} \text{H} \\ | \\ \text{---} \\ | \\ \text{OH} \end{array} \text{CH}_2\text{OH}$; that of the so-called *l*-lac-

tic acid, whose salts are dextrorotatory, is probably $\text{COOH} \begin{array}{c} \text{H} \\ | \\ \text{---} \\ | \\ \text{OH} \end{array} \text{CH}_3$; furthermore, the

absolute space formula of *d*-malic acid must be represented by $\text{COOH} \begin{array}{c} \text{OH} \\ | \\ \text{---} \\ | \\ \text{H} \end{array} \text{CH}_2\text{COOH}$

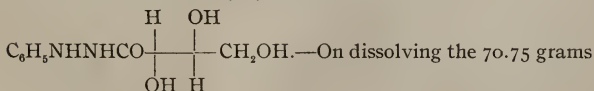
because it is formed by the reduction of *d*-tartaric acid with hydriodic acid (cf. Bremer: Ber. d. chem Ges., **8**, 1594, and **13**, 352).

grams of *l*-glycerinic quinine mentioned above gave, on distilling off the water at reduced pressure, 17.5 grams of quinine salt which, dissolved in 35 cc. absolute alcohol, gave 9.45 grams *d*-glycerinic quinine melting between 187° and 188°. This, crystallized once more from 37 cc. absolute alcohol, gave 6.6 grams of anhydrous *d*-glycerinic quinine in the form of crystalline needles with no change in the melting point; the specific rotation at 20° was found to be $-126^{\circ}.58$; $d = 1.011$; $p = 4.004$, *i. e.*, 0.7746 grams substance and 18.5688 grams water; found $[\alpha]$ in a 1 dm. tube = $-5^{\circ}.124$.

The 6.6 grams quinine salt was now converted into the free acid and then into the calcium salt; the latter gave from 15 cc. each of water and alcohol 1.7 grams *d*-glycerinic calcium melting at 136°. The specific rotation of this salt at 20° was found to be only $-10^{\circ}.20$, which shows that a small amount of the racemate was still present; $d = 1.011$; $p = 4.004$, *i. e.*, 0.6205 gram substance and 14.8749 grams of water; found $[\alpha]$ in a 1 dm. tube = $-0^{\circ}.413$.

d-Glycerinic Brucine.—The 1.7 grams calcium *d*-glycerinate, $[\alpha]_D^{20} = -10^{\circ}.20$, gave, on treatment with 0.66 gram oxalic acid, etc., 1.1 grams of the free acid which was converted by means of 4 grams of brucine into a salt; this, crystallized from 2.5 cc. water and 25 cc. absolute alcohol, gave a large amount of crystalline plates melting at 222°. These lost no weight over sulphuric acid *in vacuo* and gave a specific rotation of $-33^{\circ}.2$ at 20°; $d = 1.011$; $p = 3.992$, *i. e.*, 0.6986 gram substance and 16.8006 grams of water; found $[\alpha]$ in a 1 dm. tube = $-1^{\circ}.34$.

1-Threonic Acid Phenylhydrazide,



—On dissolving the 70.75 grams high-melting brucine salts (in two crops), referred to above, in 35 cc. water and 350 cc. absolute alcohol, 32.1 grams of crystals melting from 212° to 213° separated out within two hours; these, on recrystallization from 16 cc. water and 160 cc. absolute alcohol, gave 16.4 grams salt with no change

in melting point; the latter finally gave, with sodium hydroxide, etc., 3.9 grams of gum which, on standing in the cold with 4 cc. each of alcohol and phenylhydrazine, gave 2.75 grams of crude *l*-threonic phenylhydrazine, melting at 155° after washing well with cold alcohol. Recrystallized from 75 cc. absolute alcohol, this gave 1.95 grams of transparent rhombic plates, melting at 158° , and the filtrate, concentrated to 20 cc., gave a second crop, 0.35 gram, with the same melting point. An analysis and optical investigation gave the following result:

0.1891 gram, dried *in vacuo*, gave 0.3686 gram CO_2 and 0.1144 gram H_2O .

0.1694 gram gave 19.5 cc. N at 20° and 744.4 mm.

	Calculated for $\text{C}_4\text{H}_{14}\text{O}_4\text{N}_2$.	Found.
C	53.10	53.11
H	6.19	6.72
N	12.40	12.88

$d = 1.012$; $p = 4.68$, *i. e.*, 1.0122 grams substance and 20.5940 grams of water; found $[\alpha]$ in a 2 dcm. tube = $-2^{\circ}.953$, whence $[\alpha]_D^{20} = -31^{\circ}.17$. The value given by Nef,¹ $-26^{\circ}.88$, is too low, owing to an error on my part in calculating the concentration and also the density; that determination corrected was: $d = 1.012$; $p = 4.56$, *i. e.*, 0.7180 gram substance and 15.1141 grams water; found $[\alpha]$ in a 2 dcm. tube = $-2^{\circ}.86$, whence $[\alpha]_D^{20} = -30^{\circ}.98$.

The Brucine Salt of l-Threonic Acid.—Two and three-tenths grams *l*-threonic hydrazide, on hydrolysis, gave 1.05 grams of lactone gum and an optical determination gave: $d = 1.011$; $p = 4.00$, *i. e.*, 1.05 grams substance and 25.20 grams of water; found $[\alpha]$ in a 2 dcm. tube = $-2^{\circ}.42$, whence $[\alpha]_D^{20} = -29^{\circ}.9$. The specific rotation of various preparations of *l*-threonic lactone gum was, however, in different cases found to vary between -20° and -30° . On treating the 1.05 grams crude lactone, just referred to, with 3.5 grams of brucine and crystallizing the resulting salt from water and alcohol, 2.5 grams of long, narrow crystalline plates melting at

¹ Ann. Chem. (Liebig), **357**, 235.

213° to 214° were obtained. These, dissolved again in 2.5 cc. water and 25 cc. hot absolute alcohol, gave 2.1 grams of transparent plates, melting from 213° to 214°. An optical determination gave: $d = 1.011$; $p = 3.98$, *i. e.*, 0.9401 gram substance dried *in vacuo* and 22.6674 grams of water; found $[\alpha]$ in a 2 dcm. tube = $-2^{\circ}.61$, whence $[\alpha]_D^{20} = -32^{\circ}.40$.

The space formula of *l*-threonic acid was now determined by its almost quantitative transformation by oxidation to *l*-tartaric acid: 0.8 gram of the lactone was heated for 44 hours at 50°–60° with 4.2 grams of nitric acid (sp. gr. 1.228). On distilling off the excess of nitric acid under 15–30 mm. pressure (outside bath finally at 100°), 0.8 gram of a partly crystalline residue was left in the distilling flask. This, digested for six hours on the boiling water bath with 1.5 grams of powdered calcium carbonate and 600 cc. water, took up half a gram of calcium carbonate and only 0.05 gram calcium oxalate was found with the excess of calcium carbonate. The aqueous filtrate, concentrated to 50 cc., gave 0.85 gram very small, transparent crystals; these required 350 cc. boiling water for solution and gave, on treatment with 0.39 gram crystallized oxalic acid, etc., a crystalline acid, which, when dissolved in 40 cc. acetone, filtered and allowed to evaporate in an open dish, left 0.25 gram crystals of *l*-tartaric acid, melting at 169°–170°. This was proved as follows: An optical investigation gave: $d = 1.012$; $p = 3.013$, *i. e.*, 0.2448 gram substance and 7.8786 grams of water; found $[\alpha]$ in a 1 dcm. tube = $-0^{\circ}.435$, whence $[\alpha]_D^{20} = -14^{\circ}.26$. On converting the free acid back to the lime salt, etc., this gave the following results on analysis:

0.2261 gram air-dried salt, on ignition, left 0.0501 gram CaO.

	Calculated for $\text{CaC}_4\text{H}_4\text{O}_6 \cdot 4\text{H}_2\text{O}^1$	Found.
Ca	15.38	15.83

A preparation of pure *d*-tartaric acid, recrystallized as directed above for the *l*-compound, melted at 169°–170°, and an optical determination gave: $d = 1.012$; $p = 3.058$, *i. e.*,

¹ Anschütz: Ann. Chem. (Liebig), **226**, 201.

0.9992 gram substance (dried *in vacuo*) and 31.7000 gram of water; found $[\alpha]$ in a 2 dcm. tube = $+0^{\circ}.988$, whence $[\alpha]_D^{20} = +15^{\circ}.96$. The acid obtained by me from the oxidation of *l*-threonic acid lactone was therefore obviously the antipode, *l*-tartaric acid.

d- and l-Glycerinic Acid by the Action of Fehling's Solution on Galactose.—The alcoholic filtrate from the 2.75 grams of *l*-threonic hydrazide, mentioned above, which contained the alcohol-soluble and gummy acid phenylhydrazides, gave back, on hydrolysis, 2 grams of gum. This was united with 12.2 grams of acid gum obtained from the main portion of the 70.75 grams of high-melting brucine salts and another fraction, 10.4 grams, of high-melting brucine salts from fraction D (see above summary), by the action of sodium hydroxide, etc. The combined acid gums were boiled in aqueous solution with an excess of powdered quinine in the usual way and the salts obtained, on crystallization from water, gave 8.9 grams of *l*-glycerinic quinine, melting from 160° to 175° . The remaining quinine salts, easily soluble in cold water, then gave, on crystallization from absolute alcohol, 6.25 grams of salt melting at 160° . This, on treatment with sodium hydroxide, etc., gave 2 grams of free acid from which were obtained, with 2 cc. alcohol and phenylhydrazine, 1.3 grams *l*-threonic phenylhydrazide, melting at 155° – 158° , and 0.3 gram oxalyl phenylhydrazide, melting from 230° to 260° . The gummy, alcoholic soluble hydrazides, on hydrolysis, gave back 0.7 gram of acid gum, which was united with the acids obtained from the non-crystalline quinine salts.

The 8.9 grams of *l*-glycerinic quinine mentioned above gave with sodium hydroxide, etc., 2.3 grams of crude acid which, on conversion into the calcium salt and crystallization from water and alcohol, gave 2.4 grams of practically pure calcium *l*-glycerinate, as shown by the following: An optical determination gave: $d = 1.011$; $p = 4.008$, *i. e.*, 0.3396 gram substance, dried *in vacuo*, and 8.1326 grams of water; found $[\alpha]$ in a 1 dcm. tube = $+0^{\circ}.55$, whence $[\alpha]_D^{20} = +13^{\circ}.57$ for the hydrated salt.

0.3858 gram salt, on ignition, left 0.0769 gram CaO.

	Calculated for $\text{Ca}(\text{C}_6\text{H}_6\text{O}_4)_2 \cdot 2\text{H}_2\text{O}$.	Found.
Ca	13.99	14.23

The acids recovered from the gummy quinine salts and hydrazides amounted in all to 9.2 grams; these, on acylation, gave 11 grams of acylated gums soluble in ether. These were separated by means of aqueous soda solution and ether, as directed by Nef,¹ into 6.3 grams acylated glycerinic acid and 2.15 grams of neutral acylated threonic and erythronic lactones. The acylated glycerinic acid, on threefold hydrolysis, gave 4 grams of acids; 0.45 gram of this, on treatment with concentrated hydrogen iodide, as directed by Nef,² gave 0.40 gram β -iodpropionic acid melting from 81° to 83° . Hence, practically only glycerinic acid was present in this portion. The remainder, 3.5 grams, on conversion into the calcium salt, gave, by crystallization from water, 2.1 grams glycerinic calcium melting at 135° , and, by precipitation with alcohol, 2.5 grams of lime salts. The former was found to be optically inactive and on analysis gave the following result:

0.2434 gram, dried *in vacuo*, left, on ignition, 0.0469 gram CaO.

	Calculated for $\text{Ca}(\text{C}_6\text{H}_6\text{O}_4)_2 \cdot 2\text{H}_2\text{O}$.	Found.
Ca	13.99	13.77

The 2.5 grams of precipitated calcium salts, united with one gram of an analogous calcium salt, mentioned below, was found to lose about 10 per cent. in weight on drying over sulphuric acid *in vacuo*. An optical determination and analysis then gave:

0.2594 gram, dried *in vacuo*, left, on ignition, 0.0484 gram CaO.

	Calculated for $\text{Ca}(\text{C}_6\text{H}_6\text{O}_4)_2 \cdot 2\text{H}_2\text{O}$.	Found.
Ca	13.99	13.34

$d = 1.011$; $p = 4.016$, *i. e.*, 0.4032 gram substance and 9.6362 grams of water; found $[\alpha]$ in a 1 dcm. tube = $-0^\circ.13$, whence $[\alpha]_D^{20} = -3^\circ.20$. This was probably a mixture,

¹ Ann. Chem. (Liebig), **357**, 239-240.

² *Loc. cit.*

mainly of *d*- and *l*-glycerinic calcium, containing small amounts of *l*-threonic and *d*-erythronic calcium, as proved by a further study of its behavior towards dilute nitric acid (see below).

The above mentioned 2.15 grams of neutral acylated threonic and erythronic lactones, on hydrolysis, gave 1.1 grams of gum; this, on mixing with 1.1 cc. alcohol and phenylhydrazine, gave 0.25 gram *l*-threonic hydrazide melting at 155°. The gummy, alcohol-soluble hydrazides, on hydrolysis, gave back 0.7 gram of acid which, when converted into the lime salt and precipitated by alcohol, gave one gram of salt which, before analysis, was united with the 2.5 grams of lime salts mentioned above.

On the Presence of d-Erythronic Acid in the Nonvolatile Gums Obtained from d-Galactose by Fehling's Solution.—It is apparent, from the properties of free *d*-erythronic lactone, its hydrazide, and the brucine salt, as ascertained by Ruff,¹ that traces of this acid might easily escape detection in the presence of large amounts of *d,l*-glycerinic acid. The brucine salt of *d,l*-erythronic acid, prepared from the pure *d,l*-lactone² and brucine, can easily be resolved into its optical components, as I have found,³ by crystallization from its weight of water and twice its weight of absolute alcohol. Thus, I obtained from *d,l*-erythronic brucine, which in four per cent. concentration gave $[\alpha]_D^{20} = -26^\circ.52$, by crystallization, as directed, *d*-erythronic brucine, which gave $[\alpha]_D^{20} = -23^\circ.42$; $d = 1.011$; $p = 3.99$, *i. e.*, 0.9913 gram substance dried *in vacuo* and 23.8349 grams of water; found $[\alpha]$ in a 2 dcm. tube = $-1^\circ.89$. From this brucine salt I obtained *d*-erythronic lactone, melting from 92°–93° and containing some of the *l*-form, as is obvious from the following: The specific rotation was found to be only $-23^\circ.1$ instead of $-73^\circ.3$, given for the pure substance by Ruff; $d = 1.010$; $p = 2.95$, *i. e.*, 0.3682 gram dried *in vacuo* and 12.0746 grams of water; found $[\alpha]$ in a 1 dcm. tube = $-0^\circ.69$. On treatment with phenylhydrazine and alcohol I obtained from it considerable

¹ Ber. d. chem. Ges., **32**, 3678.

² Nef: Ann. Chem. (Liebig), **357**, 248.

³ Cf. also Lespieau: Compt. Rend., **144**, 144–146; Bull. Soc. Chim., [4] **1**, 1117.

d,l-erythronic hydrazide¹ melting at 150°, as well as some pure *d*-erythronic hydrazide² melting at 126° to 127° and having a specific rotation of -21° ; *d* was not determined but taken as unity; *p* = 0.89, *i. e.*, 0.0812 gram of substance dried *in vacuo* and 8.9774 grams of water; found $[\alpha]$ in a 1 dcm. tube = $-0^\circ.19$. The experiments just described prove very sharply the correctness of the conclusions of Nef,³ namely, that it is easily possible to recognize the presence of racemic (*d,l*-) erythronic lactone, as well as to determine the presence of an excess of one of its optical components, by the phenylhydrazine treatment.

The presence of erythronic lactone in my Fehling's solution mixture was now established as follows: In the first place it was proved by experiment that 3.8 grams of *d*-tartaric acid heated for 36 hours in a bath kept between 60° and 65° with five times its weight of nitric acid, sp. gr. 1.228, remained entirely unchanged. Secondly, one gram of *d,l*-erythronic lactone melting at 92°–93° was oxidized with five times its weight of nitric acid, sp. gr. 1.218, at 55° to 65°, for 41 hours, *i. e.*, until the evolution of brown fumes had ceased; on distilling the volatile products at 20 mm. pressure, finally at 100°, 1.15 grams of crystalline residue remained. This, by treatment with an excess of powdered calcium carbonate, was converted into 0.12 gram calcium oxalate and 1.62 grams of calcium mesotartrate, $\text{CaC}_4\text{H}_4\text{O}_6 \cdot 3\text{H}_2\text{O}$, obtained in the form of large transparent cubical crystals.⁴ It is evident, therefore, from the facts presented above that *l*-threonic, as well as *d*- and *l*-erythronic acids, are oxidized almost quantitatively to the corresponding tartaric acids under the conditions described. Finally, *d,l*-glycerinic gum, when oxidized in a similar manner with nitric acid, sp. gr. 1.218, gave, besides a large amount of oxalic acid, much yellowish gummy material whose calcium salt was also yellow and very soluble in water. It is therefore clear, by application of the above data and by use of the previous observa-

¹ Nef: Ann. Chem. (Liebig), **357**, 250.

² Ruff: Ber. d. chem. Ges., **32**, 3678.

³ Ann. Chem. (Liebig), **357**, 234–5.

⁴ Cf. Holleman: Rec. Trav. Chim., **17**, 72.

tions of Nef, that the nature of the mixture of high-melting brucine salts obtained by the action of Fehling's solution on hexoses can now be pretty accurately ascertained quantitatively.

Accordingly, 19 grams of unidentified brucine salts from galactose, melting from 190° to 205° and consisting only of threonic, erythronic and glycerinic acids, now gave back, with sodium hydroxide, etc., 3.8 grams of acid gums. These, when oxidized with 5 parts of nitric acid, sp. gr. 1.218, for 40 hours, at 55° to 65° , gave, after removal of volatile products under 20 mm. pressure, finally at 100° , 3.35 grams of yellowish pasty material filled with crystals of oxalic acid. This was resolved, by treatment in aqueous solution with an excess of powdered calcium carbonate, into 1.6 grams calcium oxalate and 1.7 grams very soluble yellowish calcium salts, both obviously oxidation products of glycerinic acid; and finally into 0.58 gram calcium mesotartrate crystallizing in transparent cubes which gave the following results on analysis:

0.1462 gram of air-dry salt, on ignition, gave 0.0338 gram CaO.

	Calculated for $\text{CaC}_4\text{H}_4\text{O}_6 \cdot 3\text{H}_2\text{O}^1$	Found.
Ca	16.55	16.52

Finally, 2.6 grams of the crude precipitated and analyzed calcium glycerinate, mentioned above as containing a small amount of trioxybutyrate of calcium, gave back, on treatment with the calculated amount of oxalic acid, etc., 2 grams of acid gum; this, on oxidation with 5 parts nitric acid in the usual manner, gave 1.6 grams of yellowish, partly crystalline residue. Treatment of the oxidation products with an excess of powdered calcium carbonate gave 1.05 grams calcium oxalate and 0.15 to 0.20 gram of pure calcium mesotartrate in transparent cubes, besides some yellow, easily soluble calcium salts.

These experiments, therefore, establish beyond doubt the presence of very small amounts of erythronic acid in the mixture of nonvolatile acids obtained from galactose and

¹ Kekulé and Anschütz: Ber. d. chem. Ges., 14, 716-717.

Fehling's solution. Furthermore, the product present must be either *d*- or *l*-erythronic lactone and not the racemic form because *d,l*-erythronic lactone can easily be identified by its very difficultly soluble and high-melting hydrazide.¹ Finally, since optically active *l*-threonic lactone is formed and in relatively much larger amount, and the theory presented in the first part of this paper calls for the *d*-modification, I consider it in the highest degree probable that *d*-erythronic lactone in traces was the actual reaction product.

Summarizing, in conclusion, my results, I have obtained from 118 grams of *d*-galactose: 2.49 grams of carbon dioxide, 15.69 grams of formic acid and 102.1 grams of nonvolatile oxy acids; from the latter I have actually isolated 13 grams of *d*-galactonic acid, 5.33 grams *d*-talonic acid, 0.5 gram oxalic acid, 2.58 grams *l*-threonic lactone, traces of *d*-erythronic lactone, about 11 grams of *d,l*-glycerinic acid, and 11.75 grams of glycollic acid. A rough estimate of the relative amount of the various components present in the 102 grams nonvolatile gums obtained is as follows: glycollic acid, 20 to 30 grams; glycerinic acid, 20 to 30 grams; trioxybutyrolactones, 4 to 8 grams; hexonic acids, 20 to 30 grams.

In conclusion, I want to thank Dr. Nef for his continued help and encouragement in the course of this work.

[Contributions from the Sheffield Laboratory of Yale University.]

CLXXII.—RESEARCHES ON PYRIMIDINES:
THE ACTION OF METHYL IODIDE AND OF BENZYL
CHLORIDE UPON 2-OXY-4-METHYL-6-METHYL-
MERCAPTOPYRIMIDINE.²

[FORTY-SEVENTH PAPER.]

BY HENRY L. WHEELER AND DAVID F. MCFARLAND.

The papers so far published on the alkylation of mercaptopyrimidines, with but one exception, have been confined to a description of the results obtained from a study of 2-mer-

¹ Nef: Ann. Chem. (Liebig), **357**, 250.

² Part of a thesis presented by David F. McFarland for the degree of Ph.D., Yale, 1909.

capto-6-oxypyrimidines. In most cases 2-mercapto-6-oxypyrimidines were found to alkylate both in the 1- and, more or less, in the 3-position.¹

In the exception mentioned, Wheeler and Johnson² showed that when a compound having the opposite configuration, the mercapto group and the oxygen atom being interchanged, 2-oxy-6-methylmercaptopyrimidine for example, was treated with potassium hydroxide and either methyl iodide or benzyl chloride, 3-alkyl derivatives were obtained. No 1-derivative was observed in this particular alkylation. Since the 3-alkyl-6-mercapto derivatives pass quantitatively into the 3-alkyl compounds of uracil when boiled with hydrochloric acid, this procedure is therefore the best for the preparation of these compounds.

With this result at hand, it then became a question whether or not 2-oxy-6-mercaptopyrimidines in other cases or in general would be the best to select for the preparation of 3-alkyl derivatives. Cytosine, or 2-oxy-6-aminopyrimidine, which has a constitution analogous to these 2-oxy-6-mercaptopyrimidines, also gives the 3-alkyl derivative on methylation.³

It seems to us that any new facts in regard to methods which lead to the formation of 3-alkyl derivatives or 3-attachments are of interest since results have been obtained by Johnson and Clapp⁴ which can be explained by the assumption that uracil, thymine, and cytosine are substituted or attached to other groups in these positions in the nucleic acids.

In our preceding paper we have shown that 2-methylmercapto- and 2-ethylmercapto-4-methyl-6-oxypyrimidine give 1-alkyl derivatives, the formation of the isomeric 3-derivatives in these cases not being observed. It was therefore of especial interest, in the above connection, to study, in this case, the alkylation of the compound having the opposite configuration, namely, 2-oxy-4-methyl-6-methylmercapto-

¹ For a list of these papers see *THIS JOURNAL*, **42**, 30 (1909).

² *Ibid.*

³ Johnson and Clapp: *J. Biol. Chem.*, **5**, 163 (1908).

⁴ *Loc. cit.*

pyrimidine. This has now been done and we find that this pyrimidine, with methyl iodide and benzyl chloride, not only gives 3-alkyl derivatives but also the isomeric 1-compounds. In the case of the action of methyl iodide, the 1- and 3-isomers are formed in about equal proportions. Benzyl chloride gave more of the 3- than of the 1-benzyl compound.

The presence of a mercapto group or the absence of oxygen in the 6-position therefore appears to favor the formation of 3-alkyl derivatives. There is, however, no strict regularity in these alkylations, so that in new cases it is impossible to predict whether a 1- or 3-derivative, or a mixture of both, will result.

The starting point for the present work was the preparation of List's¹ 2-thio-4-methyluracil (I) from acetoacetic ester and thiourea. This gave 2-methylmercapto-4-methyl-6-oxy-pyrimidine (II) by List's method of alkylation.

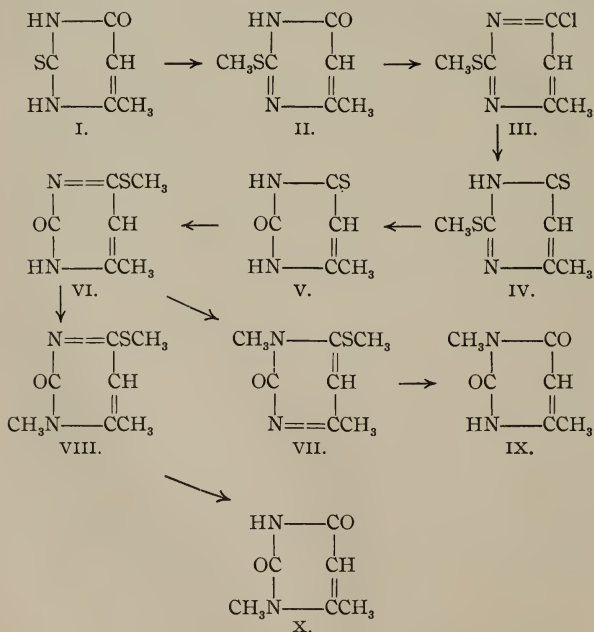
The new 2-methylmercapto-4-methyl-6-chloropyrimidine (III) was then prepared by warming the material with phosphorus pentachloride and some oxychloride. When this compound was warmed with an excess of alcoholic potassium sulphhydrate, 2-methylmercapto-4-methyl-6-thiopyrimidine (IV) was obtained, and when the latter was boiled with hydrochloric acid 4-methyl-6-thiouracil (V) resulted.

The calculated quantity of sodium ethylate and methyl iodide then gave 2-oxy-4-methyl-6-methylmercaptopyrimidine (VI). An excess of potassium hydroxide and methyl iodide, in alcoholic solution, gave 2-oxy-3,4-dimethyl-6-methylmercaptopyrimidine (VIII) and 2-oxy-1,4-dimethyl-6-methylmercaptopyrimidine(?) (VII). The latter was not obtained in a state of purity but its presence in the oily fraction was indicated by the behavior of this fraction toward hydrochloric acid. When boiled with hydrochloric acid the compounds VII and VIII gave the corresponding dimethyluracils described by Behrend,² namely, 1,4-dimethyluracil (IX) and 3,4-dimethyluracil (X).

¹ Ann. Chem. (Liebig), **236**, 12 (1886).

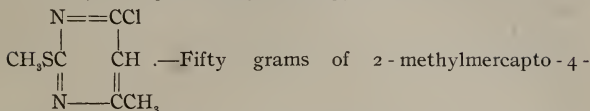
² Behrend and Dietrich: Ann. Chem. (Liebig), **309**, 265 (1899). Behrend and Thurn: *Ibid.*, **323**, 160 (1902).

The formation of 1-alkyl derivatives in this reaction could be explained otherwise, without the assumption of the formation of the compound represented by formula VII, if 2-oxy-4-methyl-6-methylmercaptopyrimidine lost mercaptan during the alkylation. 4-Methyluracil being formed, 1-alkyl derivatives would result. However, we have treated 2-oxy-4-methyl-6-methylmercaptopyrimidine with alkali, under the same conditions as those in the alkylations, and we have found that no 4-methyluracil was formed. The mercapto compound was recovered unaltered. The various steps in the synthesis of these pyrimidines may, therefore, be represented as follows:



EXPERIMENTAL PART.

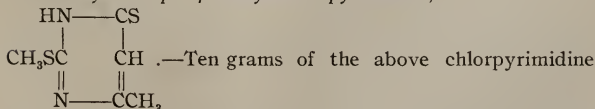
2-Methylmercapto-4-methyl-6-chlorpyrimidine,



methyl-6-oxypyrimidine were moistened with phosphorus oxychloride in a distilling bulb and then one molecular proportion (66.8 grams) of phosphorus pentachloride was added. No action was observed in the cold, and even when the mixture was warmed the reaction began only very slowly. The mass slowly liquefied with a regular, quiet evolution of hydrogen chloride. After two hours warming, the liquefaction was complete and the evolution of gas was greatly diminished. The phosphorus oxychloride was removed by distilling under reduced pressure, and the oil which remained was poured on cracked ice. It solidified to a yellow solid, which was allowed to remain in the ice water for some time and then extracted with ether. The solution was dried with calcium chloride and, on evaporation, the oil obtained was distilled at 32–35 mm. pressure. The greater part (42.8 grams) boiled steadily at 147°. This is 77 per cent. of the calculated. On cooling, this fraction solidified and then melted at 39°–40°. The substance is very soluble in all of the common solvents. When dissolved in the smallest possible quantity of petroleum ether it separated in beautiful, long needles. These were pressed on filter paper and dried in a desiccator for analysis:

	Calculated for $\text{C}_6\text{H}_7\text{N}_2\text{SCl}$.	Found.
N	16.02	16.02

2-Methylmercapto-4-methyl-6-thiopyrimidine,



were mixed with an alcoholic solution of potassium hydro-sulphide, made by saturating a solution of 19.2 grams of potas-

sium hydroxide in 60 cc. of alcohol with hydrogen sulphide. The chlor compound dissolved and very soon crystals of the potassium salt of 2-methylmercapto-4-methyl-6-thiopyrimidine began to separate. The mixture was warmed for half an hour on the steam bath and the alcohol was then evaporated. The residue dissolved almost completely in water and the solution was filtered from a slight reddish sediment. On acidifying with dilute acetic acid, the free thio compound was precipitated. The quantity obtained (9.85 grams) agreed almost exactly with the theoretical yield. This substance is very difficultly soluble in boiling water, from which it separates in light yellow, minute needles. It dissolves easily in ammonium hydroxide and separates again when the ammonia is boiled off. It is unstable in aqueous alkali and the solution takes on a dark red color. Dilute alcohol or water should therefore not be used in its preparation. Alcohol dissolves it with some difficulty, giving needle-like prisms. On standing, the alcoholic mother liquors take on a deep red color.

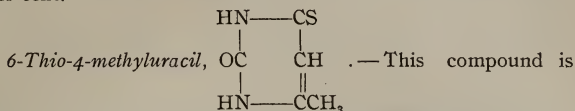
	Calculated for $C_6H_8N_2S_2$.	Found.
N	16.27	16.12

2-Methylmercapto-4-methyl-6-thiopyrimidine exhibited a characteristic behavior when heated, the product obtained at high temperatures being 2,6-dithio-4-methyluracil. This substance has been described by Gabriel and Colman.¹ When slowly heated, such as is commonly done in taking melting points, it partially melted, like a mixture, at 212° to a milky mass, which effervesced on further heating and then solidified. If the tube was placed in a bath already heated to 200° and the temperature rapidly raised, it then melted completely to a clear yellow oil at 214° . A slight elevation of temperature caused the oil to effervesce and finally solidify to a crystalline solid. On further heating this solid grew red, the color deepening until the material melted or decomposed to a red-brown oil at 280° – 290° .

One gram of the mercapto-6-thiopyrimidine was heated for

¹ Ber. d. chem. Ges., **32**, 2921 (1899).

a short time at 215°–223°. The product was treated with hot alcohol and the portion which did not dissolve was found to be also almost insoluble in boiling water. On heating, decomposition set in above 260°, but the material did not melt at 310°. A nitrogen determination gave 17.53 per cent. while the calculated for 2,6-dithio-4-methyluracil is 17.72 per cent.

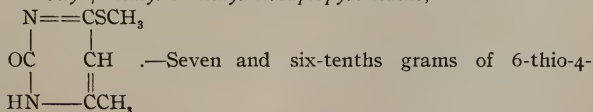


formed quantitatively by boiling 2-methylmercapto-4-methyl-6-thiopyrimidine with strong hydrochloric acid for several hours and then evaporating to dryness. Long heating is required to completely expel the mercaptan from the compound. The product is almost insoluble in alcohol and difficultly soluble in boiling water. It crystallizes in irregular, prismatic forms, has a sulphur-yellow color, but no definite melting point. When heated it decomposes above 250°.

	Calculated for C ₆ H ₆ ON ₂ S.	Found.
N	19.71	19.42

The sulphur in this compound is more firmly bound than that in 6-thiouracil or 6-thiothymine. It was not removed on long heating on the steam bath with hydrochloric acid.

2-Oxy-4-methyl-6-methylmercaptopyrimidine,



methyluracil were dissolved by warming with 2.2 grams of sodium hydroxide in 50 cc. of water and 30 cc. of methyl alcohol, and 8.5 grams of methyl iodide were added. The mixture was warmed until no further alkaline reaction was obtained. It was then evaporated to dryness. The product dissolved easily in water, leaving only a little oil, which was removed by filtration. On standing, pale yellow, flat, needle-

like crystals formed. The yield in one case was 83 per cent. of the calculated. When recrystallized from water the material melted at 174° – 175° to a clear oil. The substance was very soluble in water and alcohol, and it had a tendency to form supersaturated solutions. On this account it crystallized from water only after standing for some time. It is not appreciably volatile with steam.

	Calculated for $C_6H_5ON_2S$.	Found.
N	17.94	17.67

Action of Benzyl Chloride.—Four grams of 2-oxy-4-methyl-6-methylmercaptopyrimidine were dissolved in alcohol with 1.45 grams of potassium hydroxide. To the cooled solution, 3.3 grams of freshly distilled benzyl chloride were added and the mixture was allowed to stand for several days. The reaction then still being incomplete, the mixture was warmed for two hours on the steam bath. Some potassium chloride which separated was filtered off and the solution was allowed to evaporate spontaneously. A small amount of solid remained, mixed with a larger quantity of red oil, which had a very pungent odor. When the mixture was spread on a porous plate the oil was absorbed, leaving 1.6 grams of the sticky solid. This was very soluble in alcohol and benzene and very difficultly soluble in water. From none of these solutions could a pure crystalline substance be obtained, so the crude solid was treated directly with hydrochloric acid.

One and a half grams of the solid were digested on the steam bath with a large excess of concentrated hydrochloric acid and then evaporated to dryness. This operation was twice repeated before mercaptan was completely eliminated. The residue weighed 1.1 grams. On crystallizing from alcohol it was found to consist principally of 4-methyluracil, decomposing at 265° – 300° , and, by extracting the product with cold chloroform a very small amount of 1-benzyl-4-methyluracil was obtained. The red oil, which was absorbed in a porous plate, was extracted with boiling alcohol and treated with concentrated hydrochloric acid as above. When mer-

captan ceased being evolved, the dry residue was stirred with alcohol. This left 1.1 grams of substance undissolved, while the red color of the residue was removed. When the material was crystallized once from alcohol, Hagen's 3-benzyl-4-methyluracil, melting at 231° – 232° , was obtained. The mother liquor appeared to contain a mixture of this compound and of the 1-benzyl derivative. We conclude from the above that of the two isomers the 3-benzyl derivative is formed in larger amount.

Action of Methyl Iodide; 2-Oxy-3,4-dimethyl-6-methylmercaptopyrimidine.—Four and three-tenths grams of potassium hydroxide were dissolved in 50 cc. of methyl alcohol and 4 grams of 2-oxy-4-methyl-6-methylmercaptopyrimidine were added. This dissolved at once without warming. Three molecular proportions (11 grams) of methyl iodide were then added and the mixture was allowed to stand two days. At the end of this time considerable potassium iodide had separated and the solution no longer gave an alkaline reaction. The alcohol was then evaporated under reduced pressure and the dry residue was extracted with three portions of boiling chloroform. On evaporation of the chloroform at ordinary temperatures, slightly yellow, large, prismatic crystals mixed with oil separated. The oil did not solidify on standing for some time. It was removed by absorption in filter paper and saved for later treatment (see below).

The crystals, which weighed 2.3 grams or 53 per cent. of the calculated for dimethyl-6-methylmercaptopyrimidine, were twice recrystallized from benzene. Some brownish color was removed by boiling the solution with animal charcoal, whereupon, on filtering, splendid prisms, somewhat irregular in outline, were obtained. They melted to a clear oil at 170° – 171° , and were found to be very soluble in water and in alcohol, but only moderately so in benzene.

	Calculated for $C_7H_{10}ON_2S$.	Found.
N	16.47	16.53

This material was boiled with hydrochloric acid until it gave no test for sulphur. It was then crystallized twice from alcohol, whereupon it melted at 220° and agreed in proper-

ties with Behrend's 3,4-dimethyluracil. A nitrogen determination gave 20.06 per cent. nitrogen while the calculated for this compound is 20.00 per cent.

1, 4 - Dimethyl - 2 - oxy-6-methylmercaptopyrimidine (?).—This compound was not isolated in a pure state but its presence in the oil obtained above was indicated by the hydrolysis of the oil with strong hydrochloric acid. After digesting on the steam bath until mercaptan was no longer evolved, the solution was evaporated to dryness and the residue was crystallized from water. It separated in small prisms melting sharply, to a clear brown oil, at 260° and when mixed with a sample of β -dimethyluracil or 1,4-dimethyluracil the melting point was not lowered.

	Calculated for $C_6H_8O_2N_2$.	Found.
N	20.00	20.02

2 - Oxy - 4 - methyl - 6 - ortho-nitrobenzylmercaptopyrimidine.—Molecular proportions of 6-thio-4-methyluracil, potassium hydroxide, and *o*-nitrobenzyl chloride were mixed in dilute alcoholic solution. The mixture was then warmed until it gave a neutral reaction. When the alcohol was evaporated and the residue was treated with water the yield of crude product agreed with the calculated amount. This material dissolved fairly easily in hot alcohol and, on cooling, it gave clusters of yellow, lancet-shaped crystals melting to a clear oil at 205°.

	Calculated for $C_{12}H_{11}O_3N_3S$.	Found.
N	15.16	15.24

2 - Oxy - 4 - methyl - 6 - meta-dinitrophenylmercaptopyrimidine, prepared in a similar manner to the above, from 6-thio-4-methyluracil, potassium hydroxide, and 1-brom-2,4-dinitrobenzene, formed very small bunches of fine, mustard-yellow needles when crystallized from alcohol. It melted at 208°.

	Calculated for $C_{11}H_8O_3N_4S$.	Found.
N	18.18	18.05

NEW HAVEN, CONN.,
May, 1909.

[Contributions from the Sheffield Laboratory of Yale University.]

CLXXIII.—RESEARCHES ON HALOGEN AMINO ACIDS:
IODINE DERIVATIVES OF PARATOLUIDINE;
3,5-DIIOD-4-AMINOBENZOIC ACID.¹

[SIXTH PAPER.]

BY HENRY L. WHEELER AND LEONARD M. LIDDLE.

In the year 1848 A. W. Hofmann² showed that aniline reacts directly with iodine and that *p*-iodaniline is formed. With the exception of some remarks by Losanitsch³ and Mills,⁴ on the possibility of higher iodated products being formed in this reaction, it appears that no further attention has been given to the subject since that time.

A search in the literature also failed to reveal any description of the direct action of iodine on the homologues of aniline. The iodine derivatives of the toluidines that have been described have been made by a more round-about method.

Willgerodt and Gartner⁵ have prepared one of the two theoretically possible monoiod-*p*-toluidines, namely, 1-methyl-4-amino-2-iodbenzene, by reducing the corresponding nitro-iodtoluene.

One diiod-*p*-toluidine has been described. This was obtained by Michael and Norton⁶ by the action of iodine monochloride on *p*-toluidine hydrochloride. It was assumed, but it was not proved, that iodine entered the positions adjacent to the amino group, the substance being considered as 1-methyl-3,5-diiod-4-aminobenzene. In the same manner *p*-aminobenzoic acid also gave a diiod derivative, which was represented as 3,5-diiod-*p*-aminobenzoic acid. Michael and Norton state: "The determination of the position of the iodine atoms in the above compounds will require a separate research. The weak basic properties of diiodaniline, and the

¹ Part of a thesis presented by Leonard M. Liddle for the degree of Ph.D., Yale, 1909.

² Ann. Chem. (Liebig), **67**, 61.

³ Ber. d. chem. Ges., **5**, 157 (1872).

⁴ Ann. Chem. (Liebig), **176**, 356 (1875).

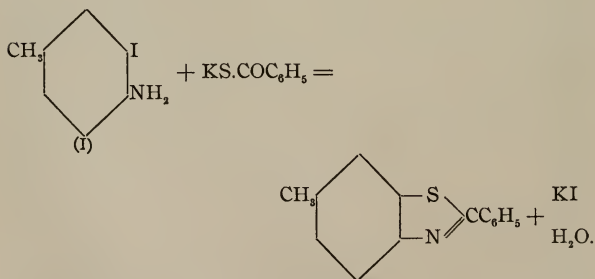
⁵ Ber. d. chem. Ges., **41**, 2813 (1908).

⁶ THIS JOURNAL, **1**, 264 (1879); Ber. d. chem. Ges., **11**, 115 (1878).

absence of basic properties in triiodaniline, indicate that the second and third iodine atoms entering the molecules have taken the ortho position to the amino group, since among the numerous known di- and trichlor- and bromanilines, only those whose halogen atoms are in the ortho position to the amido group show a like loss of basic properties."

As the writer intends to use these diiod compounds in future work, it was necessary first of all to determine their structure. This was accomplished as follows: It was first found that *p*-toluidine reacts quite smoothly with two atomic proportions of iodine and that a monoiod-*p*-toluidine is formed. This substance, being different from the material obtained by Willgerodt and Gartner, must be 1-methyl-3-iod-4-amino-benzene (I).

That this new iodine derivative has the iodine adjacent to the amino group was proved by heating the substance with the potassium salt of thiobenzoic acid, whereupon an anhydro base was formed:



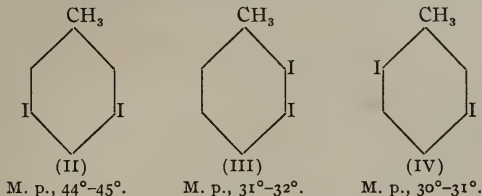
Hess¹ has previously prepared this anhydro base from "*p*-amidtoluol-*m*-sulphhydrat" and benzoyl chloride.

When this monoiod-*p*-toluidine is mixed with two atomic proportions of iodine, or when *p*-toluidine is treated with two molecules of iodine (I₄), in the presence of water and calcium carbonate, the diiod-*p*-toluidine described by Michael and Norton is easily obtained. Some dark-colored tar is

¹ Ber. d. chem. Ges., 14, 493 (1881).

formed, but, nevertheless, the yield is good. We found among the by-products *p*-azotoluene. Our direct method is the best for the preparation of this diiodtoluidine.

The diiodtoluidine, when diazotized in sulphuric acid solution and boiled with alcohol, gives a new diiodtoluene. Since one of the iodine atoms has been shown to be in the 3-position, this diiodtoluene must be one of the following new compounds:



We have now also prepared the diiodtoluenes, 1-methyl-2,3-diiodbenzene (III) and 1-methyl-3,6-diiodbenzene (IV), and we find that when crystals of any two of these three substances are mixed the mixture immediately liquefies.

It is obvious, from this and other reasons, that we are dealing here with three different diiodtoluenes.

It therefore follows that the iodine atoms in diiod-*p*-toluidine (V) are in the 3,5-position. It may also be added that our diiodtoluene (II) from diiod-*p*-toluidine is not identical with any of the other diiodtoluenes already described.¹ Since the above three diiodtoluenes complete the list of the six theoretically possible isomers, it is to be concluded that no rearrangement has taken place in diazotizing.

1-Methyl-2,3-diiodbenzene (III) was prepared from 3-nitro-2-amino-1-methylbenzene.² This was converted into 2-iod-3-nitro-1-methylbenzene by diazotizing and treating the solution with potassium iodide. By reducing with ferrous sulphate and ammonia, 3-amino-2-iod-1-methylbenzene was obtained. The preparation of this compound completes the

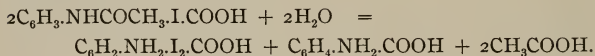
¹ 2,6-Diiodtoluene; Cohen and Miller: J. Chem. Soc., **85**, 1627 (1904). 2,4-Diiodtoluene; Neumann: Ann. Chem. (Liebig), **241**, 51 (1887). 3,4-Diiodtoluene; Willgerodt and Simonis: Ber. d. chem. Ges., **39**, 269 (1906).

² Reverdin and Crépieux: Ber. d. chem. Ges., **33**, 2498 (1900).

list of the four theoretically possible monoamino derivatives of *o*-iodtoluene. This was again diazotized and with potassium iodide gave the 2,3-diiodtoluene (III).

2,5-Diiodtoluene or 3,6-diiodtoluene (IV) was prepared from 1-methyl-2-amino-5-iodbenzene¹ by replacing the amino group with iodine.

When the acetyl derivative of monoiodtoluidine prepared from *p*-toluidine and iodine is oxidized with potassium permanganate, 3-iod-4-acetylaminobenzoic acid is formed. The isomeric 2-iod-4-acetylaminobenzoic acid, on boiling with concentrated hydrochloric acid, gives, according to Willgerodt and Gartner, 2-iod-4-aminobenzoic acid. When our acetyliodamino acid was boiled with concentrated hydrochloric acid a curious result was obtained. The acetyl group was removed, to be sure, but instead of the expected monoiodamino acid a diiodamino acid was obtained, along with a corresponding amount of *p*-aminobenzoic acid. The main reaction took place as follows:



A small amount of 3-iod-4-aminobenzoic acid, however, was obtained in one of these experiments. It was found later that this monoiodamino acid could be more easily obtained by the action of iodine monochloride on *p*-aminobenzoic acid.

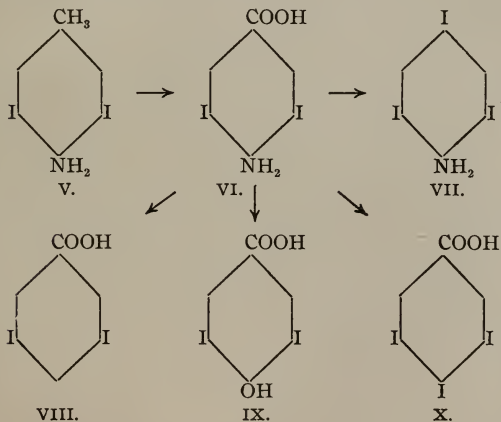
It may be added that 3-iod-*p*-acettoluide gave 3,5-diiod-*p*-toluidine on boiling with hydrochloric acid.

The diiodaminobenzoic acid formed in the above reaction proved to be identical with Michael and Norton's diiodaminobenzoic acid and was shown to be 3,5-diiod-4-aminobenzoic acid (VI) by oxidizing the acetyl derivative of 3,5-diiod-*p*-toluidine with potassium permanganate, the same acid being obtained. Michael and Norton's method is the best for the preparation of this acid.

When the potassium salt of 3,5-diiod-4-aminobenzoic acid was heated in aqueous solution with iodine, carbon dioxide was liberated and 2,4,6-triiodaniline was obtained. Iodine

¹ See following paper.

takes the place of the carboxyl group in this reaction. We have found, in this connection, that the potassium salt of *p*-aminobenzoic acid reacts in a similar manner with iodine, at ordinary temperature, giving *p*-iodaniline, and that no iodamino acid was obtained. From 3,5-diiod-*p*-aminobenzoic acid we have prepared, by diazo reactions, 3,4,5-triiodbenzoic acid (X), 3,5-diiod-*p*-hydroxybenzoic acid (IX), which is identical with the diiod-*p*-hydroxybenzoic acid obtained by Peltzer¹ by directly iodating *p*-hydroxybenzoic acid, and 3,5-diiodbenzoic acid (VIII), and in a following paper we will show that this diiodbenzoic acid is identical with 3,5-diiodbenzoic acid prepared from 3,5-dinitrobenzoic acid. This, therefore, settles the structure of these compounds.



EXPERIMENTAL PART.

3-Iod-*p*-toluidine, $\text{C}_6\text{H}_3 \begin{array}{l} \text{CH}_3(1) \\ \text{I}(3) \\ \text{NH}_2(4) \end{array}$.—When *p*-toluidine and

iodine were mixed in molecular proportions the mixture fused to a dark oil. The action took place immediately, but in

¹ Ann. Chem. (Liebig), **146**, 294 (1868).

order to complete the reaction some water, a little ether and an excess of precipitated calcium carbonate were added and the whole was warmed under a return condenser on the steam bath. When the iodine had disappeared, the ether was allowed to evaporate and the mixture was distilled in steam. A colorless oil passed over with comparative ease. The latter part of the distillation was very slow and needles formed in the condenser. This proved to be the diiod-*p*-toluidine. On long standing, the oil solidified in the form of long, radiating, colorless prisms. With the above proportions of iodine and *p*-toluidine this substance formed the chief product of the reaction. For example, 25 grams of *p*-toluidine, 54.4 grams iodine, 60 cc. water, 60 cc. ether, and 25 grams calcium carbonate gave, on distilling in steam and then extracting the distillate with ether, 45.5 grams of crude monoiod-*p*-toluidine, or 83.6 per cent. of the calculated.

When this base was distilled with steam, colorless needles separated from the turbid water on standing. These needles, the distillate product, and some material prepared from the pure hydrochloride all melted to a clear oil at 40°. The base is extremely soluble in alcohol, ether, chloroform, benzene, ligroin, or petroleum ether, and it separates from these solvents as an oil. An attempt was made to distil the base under 30 mm. pressure, but when heated decomposition set in, the oil solidified, and only a small portion distilled over. The analytical results obtained in the case of the material melting at 40° were as follows:

	Calculated for C_7H_8NI .	Found.
I	54.50	54.27
N	6.01	5.97

The salts of 3-iod-*p*-toluidine are decomposed by water.

The *hydrochloride*, $C_7H_8NI.HCl$, was prepared by dissolving the base in strong hydrochloric acid at ordinary temperature. The salt separated, on standing, in thick colorless prisms which, when rapidly heated, decomposed with effervescence at 188°. When the strong acid solution was boiled or warmed on the steam bath iodine was liberated. The

salt can be recrystallized, however, by carefully warming in water containing only a little hydrochloric acid.

	Calculated for $C_7H_8NI.HCl$.	Found.
N	5.19	5.11

The *oxalate*, $(C_7H_8NI)_2(COOH)_2$.—A hot alcoholic solution of 3-iod-*p*-toluidine and oxalic acid, when cooled, deposited thick prisms which decomposed at 119° – 120° , with effervescence. This salt could be recrystallized from alcohol.

see errata
p. 588

	Calculated for $C_{14}H_{16}N_2I_2$	Found.
N	5.03	4.87

3-Iod-*p*-tolylurea, $C_7H_8INHCONH_2$.—A nearly quantitative yield of this urea was obtained when a solution of 5 grams of 3-iod-*p*-toluidine in 20 cc. of glacial acetic acid was treated with 3.6 grams of potassium cyanate in 10 cc. of water. The solutions were quickly mixed and kept cool under running water. In a short time a heavy, crystalline precipitate formed. It was filtered and washed with cold water, in which it was nearly insoluble. Hot water or ether dissolved very little. One crystallization from alcohol gave needles; when recrystallized twice more the form had changed to thin, colorless plates, which melted to a clear oil at 187° .

	Calculated for $C_8H_9ON_2I$.	Found.
N	10.14	10.02

3-Iod-*p*-acettoluide, $C_7H_8INHCOCH_3$, from the base and acetic anhydride, was very soluble in alcohol and much less soluble in water. It crystallized from water in needles, having the thickness of a thread and several inches in length, from alcohol in long, colorless prisms, and melted to a clear oil, without effervescence, at 133° .

	Calculated for $C_9H_{10}ONI$.	Found.
N	5.09	5.07

Action of Hydrochloric Acid.—Two grams of 3-iod-*p*-acettoluide were boiled with 20 cc. of concentrated hydrochloric

acid. At first 3-iod-*p*-toluidine hydrochloride (?) separated in a granular cake, but on further boiling this suddenly went into solution. The solution was boiled until faint traces of iodine vapor were noticeable. It was then cooled and the tar which separated was dissolved in acetic acid, precipitated with ammonia, and then crystallized from alcohol. The product formed long, colorless needles melting at 125°. It proved to be 3,5-diiod-*p*-toluidine.

3-Iod-*p*-benztoluide, $C_7H_6INHCO C_6H_5$.—When 3-iod-*p*-toluidine and thiobenzoic acid were mixed, in molecular proportions, and warmed on the steam bath, the liquid produced evolved hydrogen sulphide and then solidified to a mass of crystals. Two recrystallizations from alcohol gave long, colorless needles, which melted without effervescence at 161°.

	Calculated for $C_{14}H_{12}ONI$.	Found.
N	4.15	3.87

Benzenyl-4-amino-3-thiocresol, $C_7H_6 \begin{array}{c} \diagup S \\ \diagdown N \end{array} CC_6H_5$.—Five

grams of 3-iod-*p*-toluidine and 10 grams of potassium thiobenzoate were heated in an oil bath for one and one-half hours at 240°–250°. The cake thus formed was pulverized and thoroughly extracted with hot water. The insoluble material weighed 7.8 grams. It was dissolved in concentrated hydrochloric acid and treated with animal charcoal. The solution then deposited a light yellow, crystalline substance, which melted at 123°–124°. It contained sulphur, and by analysis and the formation of a hydrous platinum double salt it was shown to be identical with the anhydro base obtained by Hess.¹

	Calculated for $C_{14}H_{11}NS$.	Found.
N	6.22	6.32

The Platinum Double Salt, $(C_{14}H_{11}NS.HCl)_2PtCl_4.H_2O$.—The yellow precipitate produced by platinum chloride in the hydrochloric acid solution of the base was recrystallized from

¹ *Loc. cit.*

dilute hydrochloric acid. It formed yellow needles, which were dried over sulphuric acid.

	Calculated for $C_{28}H_{24}N_2S_2Cl_6Pt.H_2O$.	Found.
H ₂ O	2.04	2.17
Pt	22.38	21.94

3-Iod-5(?)-nitro-*p*-acettoluide, $C_7H_6I.NO_2.NHCOCH_3$.—3-Iod-*p*-acettoluide (3.3 grams) was dissolved in nitric acid (26.5 cc., sp. gr. 1.5) cooled with ice water. When all was added the solution was poured upon ice. The precipitate, after washing and drying, weighed 2.8 grams, or 71.7 per cent. of the calculated. It dissolved with difficulty in cold, dilute alkali and was reprecipitated unaltered by hydrochloric acid. For analysis it was purified by crystallizing several times from alcohol. It first formed needles, then prisms, which finally melted at 202°–203°.

	Calculated for $C_{10}H_9I_2N$.	I.	Found.	II.
N	8.75	8.73		8.84

3,5-Diod-*p*-toluidine, C_6H_2 $\begin{matrix} \nearrow CH_3 (1) \\ \nearrow I (3) \\ \nearrow I (5) \\ \searrow NH_2 (4) \end{matrix}$. — When *p*-toluidine

and iodine were mixed in the proportion of one molecule of the former to two (I₄) of the latter and then warmed, in the presence of ether, water, and calcium carbonate, a little iodine always remained uncombined. With a slight excess of *p*-toluidine the iodine disappeared.

In one preparation, for example, 171 grams of iodine were mixed with 38 grams of *p*-toluidine (the calculated amount being 36 grams). Fifty cc. of ether, an equal volume of water, and 70 grams of precipitated calcium carbonate were added. The mixture was warmed on a return condenser for some time. On distilling in steam it was found that no monoiod-*p*-toluidine came over. The residue in the flask was filtered and extracted by boiling with a liter of alcohol. The solution was allowed to cool, filtered, and the filtrate returned to the flask, and a second extraction was made. After this

operation had been repeated a number of times, about 86 grams of crude, more or less dark, 3,5-diiod-*p*-toluidine was obtained. This is 79 per cent. of the calculated. The final mother liquor contained a black tar. The base can be obtained pure by boiling the alcoholic solution with animal charcoal. It formed, when purified, extremely long, slender needles, melting at 125° , and it agreed with the description of diiod-*p*-toluidine given by Michael and Norton.

3,5-Diiod-*p*-acetoluide, $C_7H_5I_2NHCOCH_3$, from the base and acetic anhydride, by warming on the steam bath, crystallized from alcohol, in thick, colorless prisms which melted at 226° .

	Calculated for $C_9H_9ONI_2$.	Found.
N	3.49	3.46

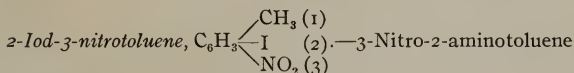
3,5-Diiodtoluene.—Ten grams of 3,5-diiod-*p*-toluidine were dissolved in 130 cc. of strong alcohol, and 5 cc. of concentrated sulphuric acid were then added. The hot, alcoholic solution was diazotized with powdered sodium nitrite (5 grams), which was added in small portions. After each addition the mixture was boiled until the evolution of nitrogen had nearly ceased. When the product was poured into cold water an emulsion was obtained. This was extracted with ether, the ether evaporated, and the dark-brown oil which remained was distilled in steam. A light yellow oil passed over, which soon solidified to a mass of yellow needles. It weighed 5.75 grams, or about 60 per cent. of the calculated amount. The substance was very soluble in ether, petroleum ether, benzene, and hot alcohol. From alcohol it deposited in bunches of light yellow spikes, which melted at 44.5° – 45.5° . It was insoluble in water, acids, or alkali.

	Calculated for $C_7H_6I_2$.	Found.
I	73.83	73.97

3,4,5-Triiodtoluene.—Ten grams of 3,5-diiod-*p*-toluidine were dissolved in 40 cc. of cold, concentrated sulphuric acid and the mixture was diazotized at 0° with 4 grams of powdered sodium nitrite. The solution was allowed to stand for

three hours and was then poured on cracked ice. A little amorphous material was filtered from the cold solution and 18 grams of potassium iodide in 35 cc. of water were added. The black diazo iodide which was formed was warmed on the steam bath until the evolution of gas had ceased and a heavy, black oil lay on the bottom of the flask. When cool, the oil solidified. It weighed 11.5 grams, or 88 per cent. of the calculated. It was insoluble in water, acid, and alkali, but it was fairly soluble in alcohol. Three recrystallizations from alcohol gave long, silky, colorless needles which melted at 122° – 123° .

	Calculated for $C_7H_5I_3$.	Found.
I	81.06	80.81



was prepared in the manner described by Reverdin and Crépieux.¹ Twenty-seven and one-half grams of this were dissolved in 65 cc. of cold, concentrated sulphuric acid and 18.7 grams of powdered sodium nitrite were added. The mixture was allowed to stand at 0° for four hours and was then poured on ice. An orange-red precipitate formed, but it dissolved almost immediately. It is probable that little or no diazotization took place in the strong sulphuric acid solution but that the nitrous acid acted on the finely divided precipitate when the solution was poured on ice. The cold, pale-yellow solution was treated with 132.5 grams of potassium iodide in 250 cc. of water. The red diazo iodide which formed was decomposed by warming on the steam bath, nitrogen was evolved, and a heavy, black oil separated. A little sodium bisulphite was added and the oil was distilled with steam. A light yellow oil with an aromatic odor easily passed over and finally solidified. From alcohol it crystallized in light yellow plates, which were not at all like the orange-red nitrotoluidine. The plates melted at 67° – 68° . The yield was 40.5 grams, or 85 per cent. of the calculated.

¹ Ber. d. chem. Ges., **33**, 2498 (1900).

	Calculated for $C_7H_6O_2NI$.	Found.
N	5.32	5.30

2-Iod-3-aminotoluene.—Fifteen grams of 2-iod-3-nitrotoluene were placed in a one-liter flask with 160 grams of ferrous sulphate. Three hundred cc. of hot water dissolved the ferrous sulphate and melted the nitrotoluidine. Three hundred cc. of concentrated ammonia were added and the flask was closed with a tube provided with a trap. After twenty hours warming on the steam bath the precipitate had become black and had noticeably settled. The mass was then cooled and an attempt was made to distil with steam. Practically nothing came over. The precipitate was filtered and extracted with alcohol and the alcohol was distilled off on the steam bath. The oil that remained now distilled rapidly with steam and even the precipitate which had been extracted with alcohol gave a further quantity of oil. When cooled, the oil solidified. The yield was about 50 per cent. of the calculated. It was purified by dissolving in dilute sulphuric acid and precipitating with ammonia. It was nearly insoluble in water and formed colorless, flat, elongated prisms melting at 41° – 42° . It dissolved easily in alcohol and ether and was volatile with these solvents. The hydrochloride and sulphate were difficultly soluble in water. It was dried over sulphuric acid for analysis.

	Calculated for C_7H_8NI .	Found.
N	6.01	5.90

2-Iod-3-acettoluide, prepared from the base and acetic anhydride, was readily soluble in alcohol. From water it crystallized in colorless needles which melted at 135° . It sublimed in long, silky, hairlike crystals.

	Calculated for $C_9H_{10}ONI$.	Found.
N	5.09	5.07

2,3-Diiodtoluene.—Five grams of 2-iod-3-aminotoluene formed a crystalline precipitate, consisting of a difficultly soluble sulphate, when added to a cold mixture of 15 cc. of

concentrated sulphuric acid and 75 cc. of water. The mixture was cooled to 0° and 2.2 grams of powdered sodium nitrite were slowly added. It dissolved almost completely in about two hours, and finally entirely on adding 10 cc. more water. The solution was then added to 17 grams of potassium iodide in 50 cc. of ice water. This produced a bulky, bright red precipitate which, on warming, changed to a heavy, dark oil. This was taken up in ether and filtered from a small amount of red material and an attempt was made to distil in steam, but very little oil passed over. On cooling, the undistilled residue became solid. It was filtered off and crystallized from alcohol by dissolving at ordinary temperature and then cooling in a freezing mixture, as otherwise it separates as an oil. Colorless plates were obtained, which melted at 31° – 32° . The melting point was not altered by recrystallizing. When this material was mixed with 3,5-diiodtoluene or 2,5-diiodtoluene the mixture immediately liquefied.

	Calculated for $C_7H_6I_2$.	Found.
I	73.83	74.21

This diiodtoluene is readily soluble in organic solvents.

3-Iod-4-acetaminobenzoic Acid.—Eighteen grams of 3-iod-*p*-acetatoluide were suspended in 750 cc. of hot water and 36 grams of magnesium sulphate added. The whole, in a twelve-liter flask, was stirred and kept hot by forcing steam through the mixture. A one per cent. solution of potassium permanganate containing 31.5 grams of the salt was added, slowly at first but more rapidly as the volume of the solution increased. When all of the permanganate had been added the solution was kept hot for one hour and the excess of permanganate was reduced with alcohol. The manganese dioxide was filtered off and washed and the large volume of colorless solution was evaporated to about 600 cc. The solution, when cooled, deposited 0.8 gram of unaltered acetyl compound. When the clear filtrate from this was acidified with hydrochloric acid it gave 13.9 grams of nearly pure acid, or 73 per cent. of the calculated. The

substance was difficultly soluble in hot water and very soluble in hot alcohol or dilute alkali. It formed bunches of needles from water, and long, colorless prisms from alcohol. It melted to a yellow oil at 230° .

	Calculated for $C_9H_8O_3NI$.	Found.
N	4.59	4.55

2-Iod-3-acetaminobenzoic Acid.—This was prepared by oxidizing 2-iod-3-acettoluide with permanganate as above. The proportions used were 6.5 grams of 2-iod-3-acettoluide, 12 grams magnesium sulphate, and 500 cc. of water. To this was added a one per cent. solution of 12 grams of potassium permanganate. Under these conditions the yield was 4 grams, or about 55 per cent. of the calculated. The acid separated from alcohol in needlelike prisms, which melted to a red oil at 199° .

	Calculated for $C_9H_8O_3NI$.	Found.
N	4.59	4.75

3,5-Diod-4-aminobenzoic Acid.—When the above 3-iod-4-acetaminobenzoic acid was boiled with concentrated hydrochloric acid the main product was not the expected mono-iodaminobenzoic acid but, instead, a mixture of 3,5-diiod-4-aminobenzoic acid and *p*-aminobenzoic acid.

Seven and four-tenths grams of 3-iod-4-acetaminobenzoic acid were boiled for several minutes with 50 cc. of concentrated hydrochloric acid. A portion remained insoluble. This material (3.7 grams) was filtered off and it was found that it did not melt at 350° . It was insoluble in water, alcohol and ether. It was purified by dissolving in ammonia and precipitating with acetic acid. This treatment gave minute needles which agreed in properties with the acid obtained by Michael and Norton from iodine monochloride and *p*-aminobenzoic acid.

	Calculated for $C_7H_5O_2NI_2$.	Found.
I	65.29	64.45
N	3.60	3.73

The hydrochloric acid filtrate from the above was evaporated to dryness and the residue taken up in hot ammonium hydroxide. The addition of acetic acid then gave a small amount of diiodamino acid. The filtrate from this was again evaporated to dryness and the residue was crystallized from water. The solution deposited a mixture which consisted mainly of large, brown crystals. These were picked out and recrystallized twice from water. The product was free from iodine and it melted at 185° . It was easily soluble in water, alcohol, and ether. A nitrogen determination gave results agreeing with those calculated for *p*-aminobenzoic acid.

	Calculated for $C_7H_7O_2N$.	Found.
N	10.27	9.94

In order to further identify the above diiodamino acid with that obtained by Michael and Norton, the sodium salt was prepared by dissolving the acid in warm sodium hydroxide. Long, colorless, shining needles separated which, air-dried, gave the following results for water:

0.3343 gram substance lost 0.0602 gram at 160° .

	Calculated for $C_7H_4O_2NI_2Na \cdot 5H_2O$.	Found.
H_2O	17.96	18.01

The material therefore agrees in every respect with Michael and Norton's descriptions.

3,5-Diiod-4-aminobenzoic Acid from 3,5-Diiod-p-acetotoluide.—Nine and two-tenths grams of 3,5-diiod-*p*-acetotoluide were suspended in 500 cc. of hot water and 12 grams magnesium sulphate were added. Steam was passed in and 11 grams of potassium permanganate were slowly added. When the color of permanganate had disappeared the solution was concentrated and precipitated with hydrochloric acid. The yield of 3,5-diiod-4-aminobenzoic acid was poor, only 1.1 gram being obtained. It was identified by its properties and the following nitrogen determination: Found, 3.42 per cent. nitrogen; calculated, 3.60.

Ethyl Ester of 3,5-Diiod-4-aminobenzoic Acid.—In the

alkylation, with ethyl iodide, of the diiodamino acid the alkyl group might be expected to attach itself to nitrogen. It was found, however, that an ester is formed. Three grams of the potassium salt were dissolved in alcohol and warmed on the steam bath with 3 grams of ethyl iodide for a number of hours. Water was then added and the fine, hairlike needles which were precipitated were found to be insoluble in ammonia. Two crystallizations from strong alcohol gave bunches of long, colorless needles which melted to a yellow oil at 148° .

	Calculated for $C_9H_9O_2NI_2$.	Found.
N	3.35	3.13

3-Iod-4-aminobenzoic Acid.—This acid is the intermediate product in the formation of 3,5-diiod-4-aminobenzoic acid when 3-iod-4-acetaminobenzoic acid is boiled with hydrochloric acid. In one of these experiments the boiling was not as long or as vigorous as usual. When the insoluble portion was dissolved in warm ammonium hydroxide and precipitated with acetic acid a noticeable portion did not separate immediately. The diiodamino acid was filtered off and the filtrate was allowed to stand for some time. It slowly deposited bunches of light-colored, hexagonal prisms which melted at 201° – 202° . The material was easily soluble in hot water and alcohol.

	Calculated for $C_7H_5O_2NI$.	Found.
N	5.32	5.20

This acid is best prepared from *p*-aminobenzoic acid and iodine monochloride. If *p*-aminobenzoic acid is dissolved in a small volume of cold hydrochloric acid and one molecular proportion of iodine monochloride in vapor form is passed in, a precipitate forms. This is filtered off but not washed. The crude precipitate is dissolved in ammonium hydroxide and the hot solution made strongly acid with acetic acid. Any diiodamino acid present separates and is filtered off. The filtrate, on standing, deposits light brown prisms of 3-iod-4-aminobenzoic acid. If *p*-aminobenzoic acid is dissolved in a

large amount of dilute hydrochloric acid and one molecular proportion of iodine monochloride is added and the solution warmed or concentrated, 3,5-diiod-4-aminobenzoic acid results.

Action of Iodine upon p-Aminobenzoic Acid.—When the potassium salt of *p*-aminobenzoic acid in aqueous solution was treated with two atomic proportions of powdered iodine, a tar was formed which was insoluble in alkali. The compound had therefore lost the carboxyl group. It dissolved in hydrochloric acid, forming a bulky hydrochloride. The aqueous solution of this salt was boiled with animal charcoal and the base precipitated with ammonia. It proved to be *p*-iodaniline. No trace of 3-iod-4-aminobenzoic acid was obtained.

Action of Iodine upon 3,5-Diiod-4-aminobenzoic Acid.—An aqueous solution of 1.7 grams of the potassium salt of 3,5-diiod-4-aminobenzoic acid was boiled with 1.0 gram of powdered iodine. No action was apparent. The mixture was heated in a closed tube at 165° for 5 hours. The tube then contained a black precipitate and some free iodine. The whole was warmed with an excess of dilute potassium hydroxide and filtered. The filtrate gave some unaltered acid on acidifying. The black residue insoluble in alkali was crystallized from acetic acid. This gave brown needles melting at 184°. When mixed with triiodaniline the melting point was not lowered.

3,4-Diiodbenzoic Acid.—One and four-tenths grams of 3-iod-4-aminobenzoic acid were dissolved in 10 cc. of cold concentrated sulphuric acid and 0.7 gram powdered sodium nitrite were added. After standing two hours the mixture was poured on ice and filtered from a trace of impurity. The cold filtrate was treated with 3 grams of potassium iodide in 10 cc. of water and the red precipitate was decomposed by warming. Free iodine was removed by means of sodium bisulphite. The light yellow precipitate, when dry, weighed 2 grams, which is the calculated amount. It was dissolved in ammonia and precipitated by hydrochloric acid and then recrystallized three times from alcohol. It was insoluble in

water, readily soluble in alcohol, and formed arborescent needles melting to a red oil at 257° .

	Calculated for $C_7H_4O_2I_2$.	Found.
I	67.91	68.20

3,5-Diiodbenzoic Acid.—Three and four-tenths grams of 3,5-diiod-4-aminobenzoic acid were dissolved in 15 cc. of cold concentrated sulphuric acid. A large excess (1.5 grams) of powdered sodium nitrite was added and the mixture allowed to stand at 0° for two hours. The diazo solution was poured on ice and a small amount of amorphous material was filtered off. The clear yellow solution thus obtained was added, in small portions, to two volumes of boiling alcohol. When the evolution of gas had ceased the solution was cooled and diluted with considerable water. A white flocculent precipitate (1.35 grams) separated. It was dissolved in dilute sodium hydroxide and precipitated with hydrochloric acid. It was insoluble in water but dissolved easily in alcohol. It was purified by repeatedly dissolving in a few cc. of hot alcohol and pouring into a large volume of boiling water. Finally it was crystallized from 50 per cent. alcohol. It formed slightly yellow prisms, which melted to a red oil at 235° . When this was mixed with a sample of 3,5-diiodbenzoic acid prepared from 3,5-dinitrobenzoic acid the melting point was not lowered. A halogen determination gave:

	Calculated for $C_7H_4O_2I_2$.	Found.
I	67.91	68.18

3,4,5-Triiodbenzoic Acid.—Three and eight-tenths grams of 3,5-diiod-4-aminobenzoic acid were diazotized in the manner described above. When the cold diazo solution was treated with a solution of 9 grams of potassium iodide in 20 cc. of water it gave a dark red precipitate. The mixture was warmed on the steam bath until the evolution of nitrogen ceased, and the free iodine was removed with a little sodium bisulphite. The light yellow precipitate weighed 3.6 grams, or 72 per cent. of the calculated. The acid was dissolved in

ammonium hydroxide and precipitated with acetic acid. It was then crystallized three times from strong alcohol. It is easily soluble in alcohol and alkali and insoluble in water and acids. It formed bundles of needlelike prisms which melted to a red oil at 288° .

	Calculated for $C_7H_3O_2I_3$.	Found.
I	76.20	76.41

The sodium salt, $C_6H_2O_2I_3Na \cdot 2\frac{1}{2}H_2O$, prepared from the acid and sodium hydroxide, formed long, colorless needles, which were only moderately soluble in water. The salt was dried in the air and the water of crystallization was determined.

0.4642 gram salt lost 0.0367 gram at 150° .

	Calculated for $C_7H_2O_2I_3Na \cdot 2\frac{1}{2}H_2O$.	Found.
H ₂ O	7.93	7.90

3,5-Diiod-4-oxybenzoic Acid.—Six grams of 3,5-diiod-4-aminobenzoic acid were dissolved in 25 cc. of cold concentrated sulphuric acid and 3 grams of powdered sodium nitrite were added. After standing four hours the mixture was poured on ice and filtered. The yellow diazo solution was allowed to stand for some time and then warmed on the steam bath. A light yellow precipitate formed which weighed 5.4 grams, or 90 per cent. of the calculated. The substance was easily soluble in alkali and alcohol but insoluble in water. It was dissolved in dilute alkali, treated with animal charcoal, and precipitated with dilute hydrochloric acid. The material was dissolved in alcohol and precipitated with water, and this operation was repeated several times, but it still contained some impurity. Finally it was converted into the methyl ester, as described below, which, as Auwers and Reis¹ have shown, forms needles and melts at 167° . From the pure ester the acid was obtained by saponification. When it was then crystallized from alcohol it agreed in all particulars with Peltzer's diiod-*p*-hydroxybenzoic acid, obtained by direct

¹ Ber. d. chem. Ges., 29, 2360 (1896).

iodation of *p*-hydroxybenzoic acid. When heated it gave off iodine above 220° and decomposed with effervescence at about 260° . This melting point was not lowered when the substance was mixed with Peltzer's diiod-*p*-hydroxybenzoic acid, prepared by direct iodation.

	Calculated for $C_7H_4O_3I_2$.	Found.
I	65.13	64.43

The following experimental work was done by Dr. S. H. Clapp: He found that the above 3,5-diiod-4-hydroxybenzoic acid could be most conveniently prepared by dissolving *p*-hydroxybenzoic acid in water containing four molecular proportions of potassium hydroxide and then adding the calculated quantity of powdered iodine. The action took place with evolution of heat, the solution darkened, and at times the diiod acid separated before the addition of iodine was completed. In the latter case, dilute alkali was added and the addition of iodine continued. The clear solution was acidified with hydrochloric acid and the precipitate, after filtering, was boiled with water to remove any unaltered acid. It was then crystallized by dissolving in hot alcohol and precipitating with hot water. The yield of pure diiod acid was 80 to 87 per cent. of the calculated.

Methyl Ester of 3,5-Diiod-4-hydroxybenzoic Acid.—Three grams of the acid were boiled in 75 cc. of methyl alcohol with 5 drops of concentrated sulphuric acid. After three or four hours the solution was cooled, whereupon the ester separated in long, snow-white, prismatic needles. The yield was 90 per cent. of the calculated. It was practically insoluble in water but readily soluble in dilute sodium hydroxide and in alcohol. On crystallizing from alcohol it melted constantly at 166° – 167° .

	Calculated for $C_8H_6O_3I_2$.	Found.
I	62.87	63.33

Methylation of 3,5-Diiod-4-hydroxybenzoic Acid.—The dipotassium salt of 3,5-diiod-4-hydroxybenzoic acid, prepared by dissolving 30 grams of the acid in water containing 11 grams of

potassium carbonate and evaporating to dryness, was dissolved in alcohol and 40 grams of methyl iodide were added. The mixture was boiled, under a return condenser, for 5 hours, although the reaction seemed to be complete in a much shorter time. The solution was filtered from potassium iodide and evaporated to dryness. The residue was stirred with water, filtered, and then digested with dilute sodium hydroxide. The material remaining insoluble weighed 24.0 grams, or 75 per cent. of the calculated for the methyl ester of 3,5-diiod-*p*-anisic acid, $\text{CH}_3\text{OC}_6\text{H}_2\text{I}_2\text{COOCH}_3$. This ester crystallized from alcohol in long, snow-white prisms melting at 95° .

	Calculated for $\text{C}_9\text{H}_8\text{O}_3\text{I}_2$.	I.	Found. II.
I	60.77	61.01	60.74

The alkaline solution mentioned above was acidified, whereupon 4.2 grams of 3,5-diiod-*p*-anisic acid, $\text{CH}_3\text{OC}_6\text{H}_2\text{I}_2\text{COOH}$, were obtained. The same acid was obtained when the above methyl ester was warmed with dilute sodium hydroxide.

3,5-Diiod-*p*-anisic acid crystallizes from alcohol in colorless needlelike prisms. When heated it shows signs of change at about 220° and decomposes to a red oil at 255° – 256° .

	Calculated for $\text{C}_8\text{H}_6\text{O}_3\text{I}_2$.	Found.
I	62.87	62.73

p-Hydroxybenzoic acid gives a yellow precipitate or coloration in aqueous solution with ferric chloride. 3,5-Diiod-*p*-hydroxybenzoic acid and its methyl ester give no color in the cold; on boiling with ferric chloride a red color is produced.

NEW HAVEN, CONN.,
May, 1909.

LEAD SILICATES:

THERMAL ANALYSIS OF THE SYSTEM PbO-SiO_2 .

By H. C. COOPER, L. I. SHAW AND N. E. LOOMIS.¹

"Lead silicates" are such characteristic glasses that in the light of modern physico-chemical studies they are much more

¹ Reports on parts of this work were submitted to Syracuse University by Messrs. Shaw and Loomis in candidacy for the Master's degree.

properly regarded as solutions than as definite substances. The various formulae occurring in works on metallurgy and glass manufacture, in which arts "lead silicates" are of considerable importance, are, therefore, without precise meaning. It is known, however, that glass tends to crystallize when cooled too slowly and Vogt¹ reports with some uncertainty having seen incidentally some synthetic PbSiO_3 in the laboratory of L. Bourgeois (Paris, 1885) which was optically uniaxial and positive with feeble interference colors.

Of more significance are the crystallized masses which are occasionally found under the fusion hearth of a dismantled lead roasting furnace. Through the courtesy of Mr. F. L. Graves, we are in possession of some specimens bearing crystals several millimeters in diameter. Analyses given by Dana and Penfield² and by H. A. Wheeler³ point to the formula $7\text{PbO} : 4\text{SiO}_2$. Equally interesting is the mineral barysilite⁴ reported from Sweden by A. Sjögren and C. H. Lundstrom, in 1888. Specimens are much like the metallurgical by-products aforementioned and have a similar composition, $3\text{PbO} : 2\text{SiO}_2$, being the nearest empirical formula of simple ratio.

After the present research had been planned, Wl. Mostowitsch⁵ published a careful investigation of the cooling curves of PbO-SiO_2 mixtures. He observed the separation of lead oxide from solutions containing an excess of that component and noted the gradual lowering of the freezing point as the silica increased, but for most of the mixtures the undercooling was very great and the heat effects were conspicuous; there was no noticeable regularity in the freezing points. All of his cooled products seem to have been amorphous, either vitreous or "waxlike," and his conclusion was that the lead silicates are solutions of lead oxide in lead glass.

Methods of Study.—We proposed to study the heating curves instead of the cooling curves, provided the mixtures could be got to crystallize. Fortunately we succeeded in

¹ Die Silikatschmelzlösungen, Christiania, 1903, 1, 45.

² Dana and Penfield: Am. J. Sci., [3] 30, 138 (1885).

³ H. A. Wheeler: *Ibid.*, [3] 32, 272 (1886).

⁴ See Dana: System of Mineralogy.

⁵ Metallurgie, 4, 647 (1907).

preparing a long series of crystallized mixtures. In developing the methods of study we were very substantially aided by the recent work of the Geophysical Laboratory on the calcium and magnesium silicates¹ and by numerous suggestions from members of its staff.

A small Hoskins electric resistance *furnace*, insulated by an extra outer fire-clay cylinder, served admirably for the work, which was at temperatures below 900°. The melting points were at first taken in 5 cc. *crucibles*, but were subsequently taken in still smaller cylinders, or capsules, of pure platinum supported directly by the platinum-tipped porcelain tube, protecting the thermocouple (see p. 464). The temperature was easily regulated with the aid of a board of thirty incandescent lamps. A *thermo-element* with potentiometer installation was used to measure the temperature. Three thermo-elements (Pt *vs.* Pt-Rh) were furnished from the same batch (XY) of wire by the Cambridge Scientific Instrument Co., Ltd., the batch having been tested by the National Physical Laboratory (1908) up to 1300° and values assigned. The temperatures given below are based on these values. We hope shortly to be equipped for the calibration by metal melting points according to the Reichsanstalt. The temperatures can then be corrected, if necessary, without difficulty, since the melting points of the pure compounds are sufficiently constant. One of our couples remained unused, the other has been used exclusively to measure the temperature of the furnace interior, while the third has been immersed naked in the lead silicate melts. After a year's use the couple that has been used in the melts does not materially differ in thermo-electric effect from the furnace couple. The former was cleaned each time after using by dipping in hot dilute nitric acid, washing and polishing. This couple, as well as the other platinum objects in contact with the silicate, was examined with a lens regularly before being used.

The couple wires were insulated by slender tubes of Marquardt porcelain and supported by a larger encasing tube of

¹ Allen, White and Wright: *Am. J. Sci.*, [4] **21**, 89 (1906). Allen, Wright and Clement: *Ibid.*, [4] **22**, 385 (1906). Allen, White, Wright and Larsen: *Ibid.*, [4] **27**, 1 (1909).

similar material. This larger tube was continued at the lower end by a short platinum tube, to which the capsule could be attached. No current leakage effects were apparent. The cold-junction bath was at zero temperature.

The *potentiometer* was a simple instrument specially designed for this work by Dr. W. P. White, of the Geophysical Laboratory, and made by the Leeds and Northrup Company. It is provided with the proper resistance for use with a Weston Standard Cell and contains three sets of resistances and the corresponding dials, the first reading millivolts, the second tenths, and the third hundredths, of millivolts. The thousandths, or microvolts (and, in practice, usually also the hundredths of millivolts), are read from the galvanometer.

The *galvanometer* used was Leeds and Northrup's High Sensibility Galvanometer No. 2280, modified to afford a period of less than five seconds. It was mounted at such a distance from the telescope that a deflection of 20 cm. corresponded to one-tenth millivolt. The scale was renumbered to read microvolts directly. At 700° a deflection of 1 mm., which could be conveniently detected, corresponded to about one-twentieth degree. It is probable, however, that the *accuracy of the work* as a whole was limited to whole degrees. A shunt switch containing resistances to reduce the galvanometer deflection to one-tenth was of assistance as a "coarse adjustment" in using the sensitive galvanometer. Commutators of the mercury-cup type were provided for exchanging the connections of the two couples and also for putting the normal cell in circuit. The installation was sufficiently convenient for readings to be taken at quarter-minute intervals or oftener. In practice the furnace couple was read at one quarter, and the melt couple at the other three quarters, of the minute. In addition the normal cell was balanced every 5-8 minutes.

For the heating-effect determinations the capsules were filled regularly to a constant height and contained each time about six grams of the (unusually dense) mixture. The couple was always immersed to the same depth and the capsule lowered to a constant depth in the furnace chamber.

Preparation of the Substances.—It is not so easy to purify lead oxide as certain other lead compounds from which lead oxide is readily obtained. Following Faraday's¹ example, we used lead nitrate, purifying it by the method of Baeke-land.² According to his determinations the nitrate is completely converted into the oxide by heating to about 357°. We could detect no nitrous compounds in our lead oxide so prepared. In an analysis of our purified lead nitrate 0.8470 gram $\text{Pb}(\text{NO}_3)_2$ gave 0.7755 gram PbSO_4 , instead of 0.7754 gram calculated.

The silica used for the measurements given below was a pulverized quartz several times purified by Baker and Adamson, under the attention of Mr. G. P. Adamson. On evaporation with hydrofluoric acid 1.0459 grams quartz left a residue of 0.0005 gram (corrected for acid residue). Before weighing, the silica was ignited in a platinum crucible over a blast lamp for fifteen minutes, which was found to reduce it to constant weight.

In making the various mixtures the lead nitrate was added to the silica directly; the mixture was then stirred and slowly heated in a loosely covered platinum crucible in the electric furnace. After the evolution of the nitrous fumes (with almost no spattering) the mixture was heated to quiet fusion; then the crucible was given a circular motion with the tongs, replaced and allowed to cool. The solidified melt was powdered in an agate mortar, reheated in a small crucible, cooled very slowly, ground to pass through an 80-mesh sieve, and returned to the crucible. The mixture was then heated for periods of several hours at temperatures 10°–100° below the approximately known melting point. After the sintered mass had cooled with the furnace it was again put through the 80-mesh sieve, with the help of more or less grinding, and transferred to the capsule for a melting point determination. The series of mixtures was prepared on a stoichiometric basis, the percentage compositions being based on the

¹ M. Faraday: Trans. Roy. Soc., 1830, 1.

² L. Baekeland: Dissociation of $\text{Pb}(\text{NO}_3)_2$, J. Am. Chem. Soc., 26, 391 (1904).

equivalent weights¹ and care being taken to include the mixtures of simple ratios. We succeeded in crystallizing a melt containing as little as 43 equivalent per cent. PbO; this is the present limit of the series. The 48 per cent. mixture was rather slow to crystallize, while the 43 per cent. mixture crystallized only after inoculation with (an analytically negligible quantity of) the 50 per cent. substance. The difficulties involved in crystallizing the more siliceous solutions may perhaps later be obviated, but they seem at present to be disproportionately greater than the likelihood of finding interesting phenomena. The work of preparation of the mixtures is partially summarized in the table given below (p. 470).

All of the mixtures crystallized upon sintering. In case of rapid cooling of the melt those mixtures containing less than 80 equivalent per cent. PbO formed colored glasses. The manner of cooling affects the physical appearance surprisingly, even when crystalline. Lead oxide itself was incidentally obtained from lead nitrate in five forms decidedly different to the eye, *viz.*, yellow powder, reddish-brown powder, copper-colored granular material, small green lustrous flakes, large copper-colored flakes. R. Ruer reports² that lead oxide has two modifications with a transition point at 500°–600°. We shall again refer to this in connection with the consideration of eutectic points.

The Measurements of the Heating Effects.—Preliminary experiments were made with a series of mixtures on a slowly heated platinum ribbon (modified Joly Meldometer) after the manner of Day and Shepherd,³ but the confusing irregularity in the order of melting, immaterial whether powder or fragments were used, prevents us from sharing their enthusiasm for the method.

Cooling curves for a few of the melts were measured in the

¹ It seems regrettable that the compositions of such series should ever be given on a simple weight per cent. basis. A series containing a very dense substance like PbO well illustrates the difficulty imposed on the reader by such a basis. There would have to be a recalculation according to the combining weights before the combining ratios could be ascertained. PbSiO₃, for instance, contains 79 weight per cent. PbO.

² Z. anorg. Chem., **50**, 265 (1906).

³ J. Am. Chem. Soc., **28**, 1101; Am. J. Sci., [4] **22**, 265 (1906).

fore part of the work, but, like Mostowitsch,¹ we observed little of interest, except the points of first separation out of lead oxide and the marked undercoolings. Messrs. Allen and White² have called attention to the unreliability of cooling curves in the study of high melting points (see below on the melting point of lead oxide).

The heating curves were similar in general form to the cooling curves of easily crystallizing substances, showing an extended, nearly level portion at the melting point of the pure substance; in the case of the intermediate mixtures we had very little difficulty in detecting the breaks for both eutectic melting and final dissolving of the excess component. The simultaneous furnace curve³ was taken in each case, some typical diagrams being seen below (see Fig. II.). Not only does the furnace curve enable one to detect fluctuations due to irregular current supply or control of the same, but it shows the sudden rise of furnace temperature immediately following the principal melting phenomenon. In the cases of definite compounds the temperature, instead of remaining strictly constant during melting, underwent a gradual, very slow rise, generally slowest at the end of the melting. The lack of sharpness of the melting point is similar to that observed by Allen and White,⁴ the total heat absorption covering only about 10°, however, and the strongest heat absorption being, for the pure compounds, at the upper three degrees. For the sake of uniformity, the highest temperature of strong absorption was taken as the melting point.

Melting Point of Lead Oxide.—We find this to be 888°. The diagram (Fig. I.), representing a single run of two heatings and two coolings, is very instructive in that it illustrates the unreliability of cooling curves and throws some light on the selection of the proper melting point. In the first heating curve, heat absorption begins at 870° and increases up to 889°.5, about which point the temperature oscillates for a

¹ Metallurgie, 4, 647 (1907).

² Am. J. Sci., [4] 27, 3 (1909).

³ See G. K. Burgess: "Methods of Obtaining Cooling Curves," Bull. Bur. Stand., 5, 199, or Electrochem. Met. Ind., 6, 366, 373 (1908).

⁴ Am. J. Sci., [4] 27, 6 (1909).

half-minute before jumping upward. In the succeeding cooling the undercooling proceeded steadily to $855^{\circ}.5$, when the unstable liquid released itself, and the next and highest temperature to be noted was 881° . A minute later the temperature remained constant nearly two minutes at 876° , whereupon the mixture ceased to evolve heat and its temperature dropped rapidly to the furnace temperature. The next heating curve, taken without removing the couple from the melt just crys-

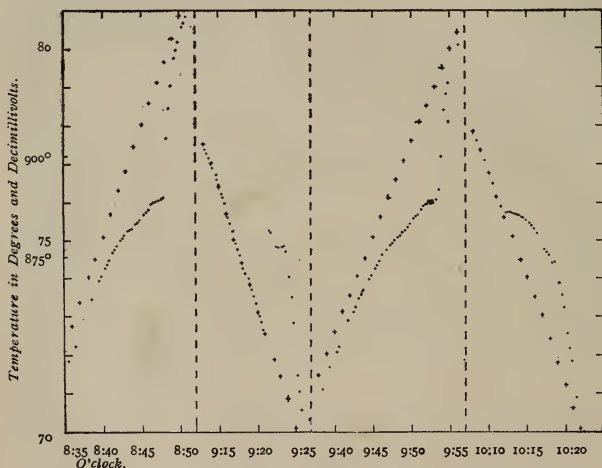


Fig. 1.—Successive heating and cooling curves of lead oxide (single experiment).

+ + + Furnace; Substance.

tallized (the first heating curve was made after the substance had crystallized and been ground), shows a beginning of absorption again at about 870° , whereupon the temperature rose steadily, fluctuated for a minute between $887^{\circ}.5$ and 889° , came to rest for half a minute at the lower temperature, and then rose very rapidly to the furnace temperature. The succeeding cooling curve is of interest, because, for whatever

reason, there was evidently less than half a degree of undercooling, the freezing temperature remaining constant for a minute at $885^{\circ}.5$, whereupon it fell at a slowly increasing rate through fifteen degrees and then dropped suddenly. While the former cooling curve shows the serious error (in this case nearly ten degrees) liable to result from relying on cooling curves, even when silica and silicates are absent (an ordinary thermocouple galvanometer might have allowed one to catch a higher maximum than the somewhat clumsy potentiometer and sensitive galvanometer, but accuracy would have to be sacrificed), the last, accidentally favorable curve affords a good determination of the freezing point and deserves comparison with the breaks in the heating curves as a reliable determination of the equilibrium point. The true melting point cannot be lower than the maximum of the last cooling curve, which is within about three degrees of the (practically constant) maximum of the heating curves. We seem justified, therefore, in taking the maximum of the heating curve as the melting point, in spite of the fact that the reason for the heat absorption beginning at a much lower temperature can only be guessed at.

The following table gives various data and observations concerning the preparation of the mixtures and the transformation points (eutectic and final melting) as determined from the various heating curves. In the cases of the more significant mixtures two or more determinations were made and the mean is given. The double data for the eutectic points in the cases of the higher mixtures are discussed below under "eutectic points."

Equivalent per cent. PbO.	Ratio PbO : SiO ₂ .	Result of slow cooling of melt.	Sintered at a furnace temperature of	Eutectic point.	Melting point.
100.0					888
90.00	9 : 1	Dark gray crystalline mass with large bright yellow patches of crystals	860 → 680	720; 727	853
87.00	...	Coarsely crystalline	712, then 690	722; 729	825
80.00	4 : 1	"	723 → 680	(723)	(723)
77.78	7 : 2	Crystalline	712, then 690	718	727
75.00	3 : 1	"	713 → 680	(716)	(716)
71.43	5 : 2	"	713 → 680	718	732
69.00	...	"	738 → 680	714	742
66.67	2 : 1	"	723 → 680	...	746
65.00	...	"	738 → 680	717	742
60.00	3 : 2	"	712, then 690	718	722
57.14	4 : 3	Upper half vitreous, lower crystalline	713 → 680	716	723
52.00	...	Smoky glass with crystal nuclei	753 → 680	718	764
50.00	1 : 1	Amber glass with crystal nuclei	753 → 680	...	766
48.00	...	Pale yellow glass with crystal nuclei	753 → 680	...	765
42.86	3 : 4	Almost colorless glass, with crystal nuclei(?)	743 → 690	...	760

A good idea of the different types of heating curves can be had from Fig. II., in which a group of actual heating curves centering about the orthosilicate ($2\text{PbO} : \text{SiO}_2$) is reproduced. The curves for 65 and 69 per cent. are very similar, the melting point of the solution, as well as the eutectic point, being well defined. In the 71.4 per cent. (5 : 2) curve the eutectic melting is the preponderant effect, while in the 66.67 per cent. (2 : 1) curve we observe only the melting effect of the pure compound.

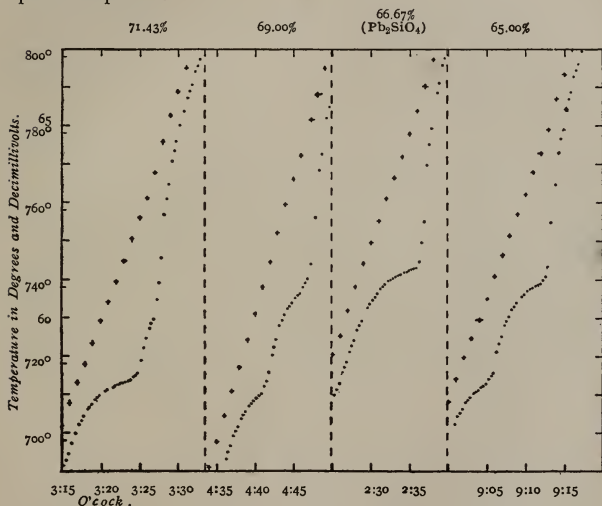


Fig. 2.—Typical heating curves arranged in series according to equivalent percentage PbO.

Equilibrium Curve.—All of the significant points are represented graphically in the melting point curve of the system, as shown in Fig. III. The maxima for the orthosilicate, Pb_2SiO_4 , and metasilicate, PbSiO_3 , leave little to be desired for sharpness.

Eutectic Points.—The eutectic point for solutions of the two silicates may be taken as 717° . The eutectic point for PbO —

Pb_2SiO_4 solutions is confused by another well-marked effect, presumably a crystallographic inversion point, which is so close to the eutectic point that neither can be definitely fixed without further microscopic study. It is not unlikely that the allotropy of lead oxide mentioned above (p. 466) is the

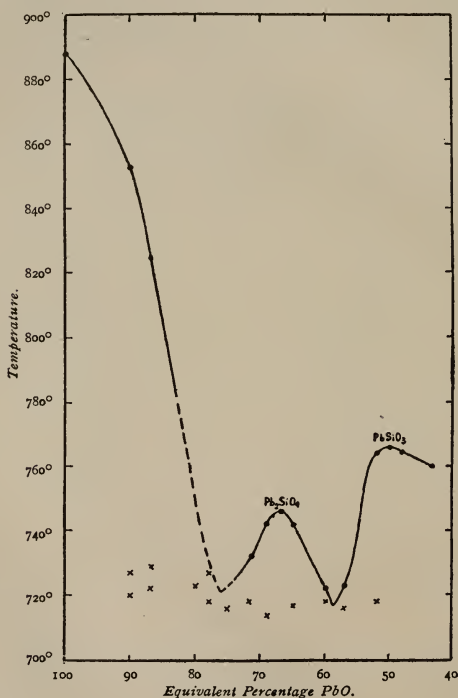


Fig. 3.—Melting point curve.

cause of the confusion. On account of this uncertainty the portion of the curve adjacent to this eutectic point is of a provisional nature.

Crystallographic Observations.—Both of the silicates dis-

covered crystallize readily under suitable conditions, described above. Microscopic measurements have shown the orthosilicate crystals to be hexagonal. They are very similar to the laminar crystals found in specimens of barysilite from Langbanshyttan, Sweden. We are planning to continue the optical studies in connection with further thermal observations. An attempt will be made to recrystallize the lead silicates from a high-temperature solvent.

The thermal analysis would indicate that the mineral barysilite and the metallurgical "lead silicate" approximate the eutectic mixture, but contain an excess of the orthosilicate. The occurrence of small single crystals scattered through the dark brown or gray mass in nearly all the specimens would confirm this inference. The optical study should be of great assistance in this connection.

Industrial Application.—The principal metallurgical value of this investigation is that it shows the existence of definite compounds which presumably participate in the processes of treating lead ores. In the glass industry the only commercial glass known to us which falls within the series studied is the "heaviest flint glass"¹ with 78 weight per cent. (49 equivalent per cent.) of lead oxide and the rest silica. Such glass undoubtedly tends to crystallize in the factory on slow cooling, for it is very close to the composition of the crystallizable silicate, PbSiO_3 .

Summary.—A large number of mixtures of lead oxide and silica, prepared in series, have been obtained crystalline by slow cooling of the melt and the heating curves have been studied. The resulting well-defined curve of melting points shows maxima for the orthosilicate and metasilicate (Pb_2SiO_4 and PbSiO_3). Some significant melting points given are: PbO , 888° ; Pb_2SiO_4 , 746° ; PbSiO_3 , 766° ; eutectic Pb_2SiO_4 - PbSiO_3 , 717° .

SYRACUSE UNIVERSITY,
August 25, 1909.

¹ Made by Schott u. Gen., Catalog Type S. 57.

OBITUARY.

SAMUEL WILLIAM JOHNSON.

Professor Johnson, whose death, after a brief illness, at his home in New Haven was announced July 21st, was born in Kingsboro, New York, on July 3, 1830. His boyhood was spent on the large farm of his father, a retired business man, and it was doubtless from him that the boy acquired his interest in those agricultural problems to which he devoted so large a part of his life. From his tenth to his seventeenth year he studied at Lowville Academy where he obtained his first knowledge of chemistry from Professor David Porter Mayhew, whose assistant he became. While there in 1847, he published his first paper, "On Fixing Ammonia."

In 1848, he fitted up a laboratory of his own, making most of his reagents himself. After teaching three years, he was able to enter Yale in 1850 and studied under Norton and Silliman. In 1853, he went to Europe and worked in the laboratories of Erdmann, Liebig, Kobel and Pettenkofer and for a short time with Frankland in England. He also attended some of the lectures of Chevreul in Paris.

He returned to Yale in 1855 as chief assistant in the Scientific School. The following year he was made professor of analytical chemistry, and in 1857 succeeded Porter in the chair of agricultural chemistry, which he occupied until 1875. He was then appointed professor of agricultural and theoretical chemistry and he continued to teach these subjects, as well as organic chemistry, until his retirement in 1895.

Even from his student days, Professor Johnson had taken an active interest in agricultural chemistry and in 1866 became a member of the first Connecticut State Board of Agriculture. It was very largely through his efforts that an act was finally passed in 1877 establishing an agricultural experiment station, the first on the continent.

He very early became a member of the American Association for the Advancement of Science, and in 1866 was elected to the National Academy of Sciences. He was long affiliated with the American Chemical Society, serving as its president in 1878. He was also one of the original members of the American Association of Official Agricultural Chemists and its president in 1888.

His books, "How Crops Grow" and "How Crops Feed,"

have been translated into half a dozen foreign languages and are the most widely read and studied books of their kind in the world. His translations of Fresenius' "Qualitative and Quantitative Analysis" are also familiar to American college students. His other publications number fifty or more papers, mostly on purely chemical subjects, although some bear on mineralogy.

REVIEWS.

DIE CHEMISCHE INDUSTRIE. Von GUSTAV MÜLLER, Kaiserl. geheimer Oberregierungsrat, Vortr. Rat im Reichsamt des Innern. Unter Mitwirkung von DR. PHIL. FRITZ BENNICSON, bei den Königl. Techn. Instituten der Artillerie. Leipzig. B. G. TEUBNER, 1909. Price, M. 11.20.

This is one of the most recent volumes in this valuable series. It deals chiefly with the commercial side of chemical industry. The chief topics are statistics of production in Germany and other countries; German internal revenue and import and export duties; German laws applying to manufacture, to storage and to the care and protection of the workman in the various industries; number of workmen employed in a given industry, their age, sex and average wage; variations in price and average dividends of an industry; syndicates of manufacturers or dealers. The chemical data given are good and clear but brief, indicating methods of manufacture and including brief historical data, but avoiding detail.

This is a thorough and useful book; while it is chiefly valuable to the merchant and the manufacturer, it contains enough of interest to a chemist to repay perusal. E. R.

A COURSE IN INORGANIC CHEMISTRY FOR COLLEGES. By LYMAN C. NEWELL, Ph.D. (Johns Hopkins), Professor of Chemistry, Boston University. Boston: D. C. Heath and Co., 1909. pp. 594. Price, \$2.

This book is intended for college students who devote a year to general chemistry. It contains as much matter as can be clearly handled in a book of the size, and the treatment is clear throughout. The electrolytic dissociation theory is introduced to explain the phenomena of neutralization, and other theoretical subjects receive clear though necessarily brief illustration. More reference is made to chemical industry than is common in books of this size. The book is illustrated by portraits of Dewar, Ramsay, Madame Curie and others. On the whole, this is a very excellent college manual. E. R.

AN INTERMEDIATE COURSE OF LABORATORY WORK IN CHEMISTRY. By EDWARD KENNETH HANSON, M.A., and JOHN WALLIS DODGSON, B.Sc. London and New York: Longmans, Green and Co. pp. 124.

This book is written to prepare students for the London Intermediate Science Examinations, and is chiefly given to well-selected and illustrated inorganic and organic preparations, and to excellent treatises on volumetric and gravimetric analysis, while the closing twenty-five pages explain just enough of qualitative analysis to enable a student to analyze simple salts, but not to analyze mixtures or minerals.

The book is well written, but can have little vogue in this country, as we always teach qualitative analysis before preparations or serious quantitative work. It may be that we are wrong; it may be urged that the setting-up and manipulation of apparatus involved in preparations, and the neatness and accuracy required for quantitative work fit a student for qualitative work, while teachers know that beginners may analyze correctly but yet develop slovenly ways hard to eradicate, and fatal to satisfactory quantitative or preparative work.

E. R.

TABLES OF PROPERTIES OF OVER FIFTEEN HUNDRED COMMON INORGANIC SUBSTANCES. By WILHELM SEGERBLOM, A.B., Instructor in Chemistry at the Phillips Exeter Academy. Exeter, N. H.: Exeter Book Publishing Co. pp. 144.

These tables give the principal properties of such substances as may reasonably be looked for in a course of qualitative analysis. The author acknowledges his indebtedness to Watts, Dammer, Comey and others, references without which, indeed, the book could not have been written. Quantitative statements of solubilities instead of the mere statements soluble or insoluble in water would add to the value of the book without increasing its volume. Mr. Segerblom's compilation should be welcomed as a ready reference book for every day in school, college and commercial laboratories.

E. R.

AMERICAN CHEMICAL JOURNAL

THE OXIDATION OF HYDROXY DERIVATIVES OF BENZALDEHYDE, ACETOPHENONE AND RE- LATED SUBSTANCES.

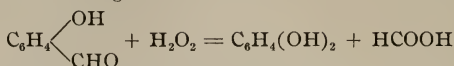
By H. D. DAKIN.

The object of the following paper is to describe a new and somewhat remarkable reaction by which polyhydric phenols result from the oxidation, under certain conditions, of hydroxy derivatives of benzaldehyde and acetophenone.¹

If *o*- or *p*-hydroxybenzaldehyde (1 mol.) is dissolved in normal aqueous caustic soda (1 mol.) and 2-3 per cent. hydrogen peroxide (1 mol.) is then added to the yellow solution of the sodium salt, a change in color is soon perceived. After a few seconds the solution becomes brownish-red and this change is accompanied by a considerable rise in temperature. On acidifying the solution it is found that practically no unchanged aldehyde remains and on extraction with solvents an almost theoretical yield of catechol or quinol is obtained. In the aqueous residue, formic acid is readily detected and if excess of hydrogen peroxide is employed, carbon dioxide resulting from the further oxidation of the formic acid is also formed. *No significant amount of hydroxybenzoic acid is formed in either case.*

¹ Cf. P. Chem. Soc., 1909.

The net result of the reaction may be expressed as follows, but, as will appear later, the equation does not satisfactorily elucidate the change:



o- and *p*-Hydroxyacetophenone behaved in similar fashion, yielding on oxidation catechol and quinol, respectively. A small but definite yield of quinol was also obtained by the oxidation of *p*-hydroxyphenylethyl ketone.

The same reaction was also found to occur in the case of the majority of halogen, hydroxy and nitro derivatives of *o*- and *p*-hydroxybenzaldehyde, as recorded in the following table. The products comprise several undescribed substituted polyhydric phenols and, as in many cases the yields are good, the reaction may prove to be of considerable value for the preparation of these substances, some of which are difficult to obtain by other methods.

On investigating the behavior of *m*-hydroxybenzaldehyde and its derivatives it was found that with a possible exception (4-methoxy-3-hydroxybenzaldehyde—iso vanillin) no similar reaction took place, and no formation of resorcinol or its derivatives was ever observed.

I. *o*- and *p*-Hydroxy Derivatives.

Substance oxidized.	Product.
2-Hydroxybenzaldehyde	Catechol
4-Hydroxybenzaldehyde	Quinol
5-Chlor-2-hydroxybenzaldehyde	4-Chlorcatechol
3,5-Dichlor-2-hydroxybenzaldehyde	3,5-Dichlorcatechol
3,5-Dichlor-4-hydroxybenzaldehyde	2,6-Dichlorquinol
5-Brom-2-hydroxybenzaldehyde	4-Bromcatechol
3-Brom-4-hydroxybenzaldehyde	Bromquinol
3,5-Dibrom-2-hydroxybenzaldehyde	3,5-Dibromcatechol
3,5-Dibrom-4-hydroxybenzaldehyde	2,6-Dibromquinol

Substance oxidized.	Product.
3,5-Diod-4-hydroxybenzaldehyde	No appreciable phenol formation
3-Nitro-2-hydroxybenzaldehyde	3-Nitrocatechol
5-Nitro-2-hydroxybenzaldehyde	4-Nitrocatechol
2-Nitro-4-hydroxybenzaldehyde	Nitroquinol*
3-Nitro-4-hydroxybenzaldehyde	No appreciable phenol formation
2,4-Dihydroxybenzaldehyde	Hydroxyquinol
3,4-Dihydroxybenzaldehyde	Hydroxyquinol
3-Methoxy-4-hydroxybenzaldehyde	2-Methoxyquinol
3-Methoxy-4-hydroxy-5-brombenzaldehyde	2-Methoxy-6-bromquinol
3-Methoxy-4-hydroxy-5-nitrobenzaldehyde	No appreciable phenol formation
3-Methoxy-4-hydroxy-2-nitrobenzaldehyde	3-Methoxy-2-nitroquinol
2-Hydroxyacetophenone	Catechol
4-Hydroxyacetophenone	Quinol
2,4-Dihydroxyacetophenone	Hydroxyquinol
2,5-Dihydroxyacetophenone	Hydroxyquinol*
2-Hydroxy-4-methoxyacetophenone	Methoxyquinol*
2-Hydroxy-4-ethoxyacetophenone	Ethoxyquinol*
4-Hydroxyphenylethyl ketone.	Quinol.

II. m-Hydroxy Derivatives.

Substance oxidized.	Product.
3-Hydroxybenzaldehyde	No phenol formation
Brom-3-hydroxybenzaldehyde	No phenol formation
2-Nitro-3-hydroxybenzaldehyde	No phenol formation
6-Nitro-3-hydroxybenzaldehyde	No phenol formation
3-Hydroxy-4-methoxybenzaldehyde	Doubtful phenol formation
3-Hydroxyacetophenone	No phenol formation.

* The four substances marked with an asterisk (*) were not actually isolated in a pure state. Their formation was inferred from characteristic qualitative reactions.

The behavior upon oxidation of a large number of other halogen, nitro, amino and methoxy derivatives of benzaldehyde and acetophenone which did not contain a free hydroxyl group in the ortho or para position was also examined but in no case could any reaction be demonstrated analogous to the one under discussion.

From the preceding statements it is clear that under the conditions prevailing in these experiments, *only those derivatives of benzaldehyde and acetophenone will yield polyhydric phenols upon oxidation which already contain a free hydroxyl group in the ortho or para position.*

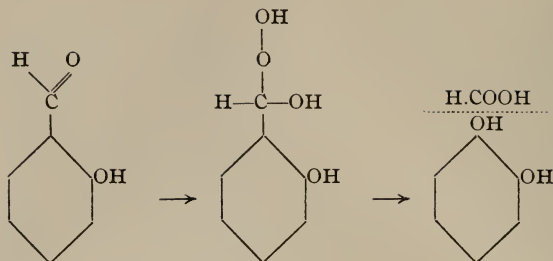
In the attempt to learn more of the conditions under which polyhydric phenols are formed by the oxidation of hydroxyaldehydes and ketones, a number of experiments were made in which oxidizing agents other than hydrogen peroxide were employed. In almost all of these experiments the sodium salt of *o*-hydroxybenzaldehyde was selected as the substance to be oxidized for the reasons that its conversion into catechol, at least when oxidized with hydrogen peroxide, takes place with especial ease, and in addition any catechol that may be formed is readily detected. It was found that sodium peroxide, barium peroxide, benzoylhydrogen peroxide ($\text{C}_6\text{H}_5\text{CO.O.OH}$) and Caro's acid, in addition to hydrogen peroxide, were all capable of effecting the oxidation of *o*-hydroxybenzaldehyde with formation of catechol. On the other hand, the employment of lead peroxide, manganese peroxide, benzoyl superoxide ($\text{C}_6\text{H}_5\text{CO.O.O.CO.C}_6\text{H}_5$), silver oxide, potassium permanganate, potassium bichromate, potassium ferricyanide, oxidation on prolonged exposure to the air, both in the presence and absence of benzaldehyde, and also oxidation in the animal organism in no case resulted in the formation of catechol, but in most cases salicylic acid was formed. The fact that oxidation of the sodium salt of *o*-hydroxybenzaldehyde, when exposed to the air, does not give catechol is perhaps somewhat surprising in view of the observations of Baeyer upon the mode of oxidation of benzaldehyde when exposed to the air. The formation of a superoxide, $\text{C}_6\text{H}_5\text{CO.O.OH}$, as an initial product of the auto-oxidation of benzaldehyde would appear to be a reaction

which, if it occurred in the case of *o*-hydroxybenzaldehyde, might be expected to result in the formation of catechol. In relation to this reaction it is interesting to note the similar behavior of vanillin and other aldehydes which yield phenols on oxidation with hydrogen peroxide but which yield the corresponding acids when allowed to undergo spontaneous oxidation by prolonged free exposure to the air.

An observation which probably is of significance in any consideration of the mechanism of the oxidation of the sodium salt of salicylic aldehyde with superoxides is the apparent dependence of the reaction upon the presence of water. Neither the sodium salt of benzoyl hydrogen peroxide nor sodium peroxide can oxidize *o*-hydroxybenzaldehyde with formation of catechol if the reaction be carried out in dry ether. In the case of sodium peroxide a yellow salt is formed which may be decomposed with ice water without any catechol being formed. On boiling the salt with water, catechol and unchanged *o*-hydroxybenzaldehyde are obtained.

It is difficult to picture the mechanism of the conversion of an *o*- or *p*-hydroxybenzaldehyde into a dihydric phenol, but several possibilities present themselves as worthy of consideration.

The fact that thus far superoxides constitute the only class of oxidizing agents which have been found capable of bringing about the reaction suggests the possibility of an intermediate formation of a superoxide such as is formed, for example, by the combination of chloral and hydrogen peroxide ($\text{CCl}_3\text{CH}(\text{OH})\text{O.OH}$). The additive compound thus produced might conceivably undergo rearrangement, with formation of a phenol and formic acid. The oxidation of *o*-hydroxybenzaldehyde according to this view might be represented as follows:



There are, however, a number of objections to such an hypothesis, for it offers no explanation of the fact that apparently only hydroxy derivatives of benzaldehyde are capable of undergoing the transformation, nor of the differing behavior of the *m*- when contrasted with the *o*- and *p*-hydroxy derivatives.

The investigations of Hantzsch upon the relation between the color and constitution of salts of the hydroxybenzaldehydes have already indicated the probable existence of two series' of salts: colorless phenolic salts of normal structure, *e. g.*, $\text{C}_6\text{H}_4(\text{OMe}).\text{CHO}$, and colored salts of quinoid structure,

e. g., $\text{C}_6\text{H}_4 \begin{array}{c} \text{O} \\ \parallel \\ \text{CHOMe} \end{array}$, and these observations appear to have a direct bearing upon the reaction under consideration.

If it be assumed that in aqueous solutions of the salts of the *o*- and *p*-hydroxy derivatives of benzaldehyde and acetophenone at least part of the substance is in the quinoid

form, $\text{C}_6\text{H}_4 \begin{array}{c} \text{O} \\ \parallel \\ \text{C(OMe)R} \end{array}$ (or in the form of the ions resulting from

the dissociation of the quinoid salt), and that the superoxides have the property of oxidizing this form but not the true phenolic salts, a number of experimental facts may be readily correlated.

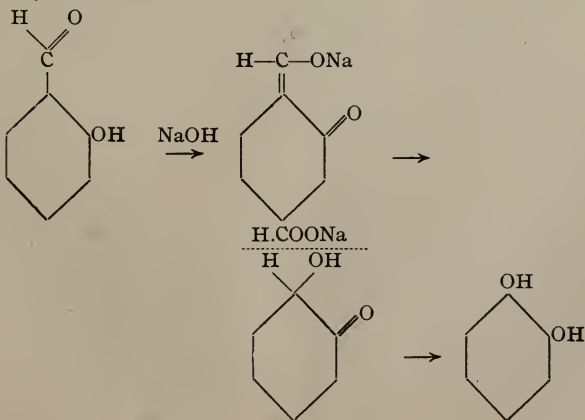
Such a theory indicates the reason why the substitution of an aldehyde grouping by an hydroxyl group upon oxidation with hydrogen peroxide only takes place when the aromatic

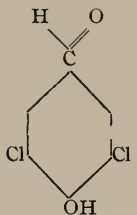
nucleus already contains at least one hydroxyl group in the *o*- or *p*-position. It can furthermore explain the reason of the inhibition of the transformation if the hydrogen atom of the hydroxyl group be replaced by an alkyl group, and in addition the nonreactivity of the *m*-hydroxy derivatives is intelligible. The difficulty of obtaining catechol by the oxidation of free *o*-hydroxybenzaldehyde may also reasonably be referred to absence of any large proportions of molecules of quinoid structure.

The fact that at least in the case of some superoxides the reaction takes place only in the presence of much water makes it appear possible that the reaction may be an ionic one.

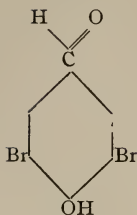
The difference in the products of the oxidation of the salts of *o*- and *p*-hydroxybenzaldehyde with superoxides on the one hand and other oxidizing agents, such as potassium permanganate, etc., on the other, may be referred to the possibility that of the two tautomeric forms in which the salts may be present in aqueous solution, the quinoid form is capable of oxidation by means of superoxides, whereas with the other oxidizing reagents, the salt reacts in the phenolic form.

The conversion of *o*-hydroxybenzaldehyde into catechol may be formulated as follows:

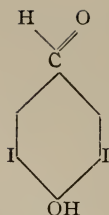




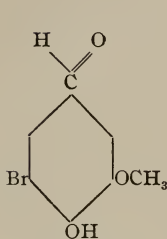
(+ reaction.)



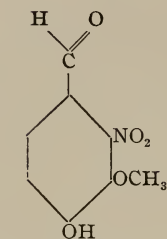
(+ reaction.)



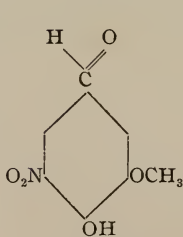
(No reaction.)



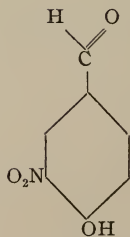
(+ reaction.)



(+ reaction.)



(No reaction.)



(No reaction.)

The table on p. 478 contains a few results which at first sight appear anomalous and require passing mention. Thus it was found that while 3,5-dichloro-4-hydroxybenzaldehyde and 3,5-dibromo-4-hydroxybenzaldehyde both gave substituted quinols upon oxidation, the corresponding 3,5-diiodo-4-hydroxybenzaldehyde did not react. A similar failure to react was shown in the case of 5-nitrovanillin and 5-nitro-4-hydroxy-

benzaldehyde, although the related 5-bromvanillin readily reacted, as did also 2-nitrovanillin. These results appear more clearly when tabulated as follows:

A consideration of the results shows that the cause of non-reactivity cannot be assigned singly to either the nature or position of the substituents but is to be sought in a combination of both factors. Hantzsch¹ has concluded from some observations upon the color of the salts of derivatives of *p*-hydroxybenzophenone that the presence of negative substituents adjacent to the hydroxyl group tends to inhibit the formation of quinoid salts, and hence the salts retain a phenolic structure. Such a view applied to the anomalous results just mentioned accords with the observed facts, but it is difficult to obtain direct evidence of its correctness, and moreover it is not clear why the 3,5-dichlor- and 3,5-dibrom-*p*-hydroxybenzaldehydes should be capable of conversion into the corresponding phenols without great difficulty while under the same conditions the corresponding 3,5-diiodo derivative is unattacked.

Incidentally in connection with the experiments recorded in this paper, a convenient method for the preparation of bromvanillin is described. The properties of the substance were more carefully studied than hitherto was the case and the position of the bromine atom was determined.

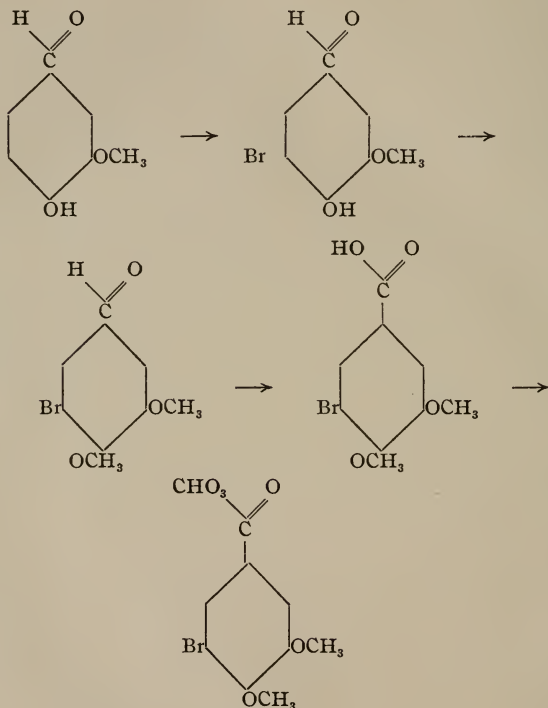
By methylation with dimethyl sulphate and potash, bromvanillin gave a bromveratric aldehyde (m. p. 65°–66°) differing from the 6-bromveratric aldehyde (m. p. 150°) obtained by Decker and Girard² from the oxidation of benzylbromisopapaverin with potassium permanganate. The bromine in bromvanillin may therefore be either in position 2 or 5. By oxidizing the bromveratric aldehyde to the corresponding acid and converting the latter into the methyl ester it was possible to decide between the two possible structures. 2-Bromveratric acid methyl ester melts at 46°, whereas the isomeric 5-brom derivative melts at 71°. ³ The product ob-

¹ Ber. d. chem. Ges., **39**, 3093 (1906).

² *Ibid.*, **37**, 3809.

³ Zincke and Francke: Ann. Chem. (Liebig), **293**, 187.

tained from bromvanillin melted at 70° , from which it is inferred that the bromine atom in the former substance occupied position 5.



EXPERIMENTAL.

Experiments on the Oxidation of Salicylic Aldehyde.—The oxidation of salicylic aldehyde to catechol is effected at least as readily as any of the other analogous reactions; accordingly this substance was selected for making a large number of trial observations.

Oxidation of Various Salts of Salicylic Aldehyde.—It was found that the sodium, potassium and ammonium salts were all readily converted into catechol by treatment with hydrogen peroxide. These experiments were conducted by dissolving 0.01 gram molecule = 1.22 grams salicylic aldehyde in 10 cc. of normal alkali and adding a slight excess of hydrogen peroxide. The liquid becomes warm and somewhat dark. On acidifying, no precipitate of unchanged aldehyde is obtained. In an experiment in which the free aldehyde (1.22 grams) and hydrogen peroxide were mixed together previously, and then small additions of caustic soda were made with vigorous shaking during the intervals, it was found that 9.0 cc. were needed to produce a permanent alkalinity to litmus, while 10.5 were needed when phenolphthalein was employed as indicator. The theoretical amount for 1 molecule was 10.0 cc. The difference between the two determinations is doubtless due to the production of carbonates from the oxidation of the formic acid produced in the reaction.

The amount of hydrogen peroxide taking part in the reaction was determined by dissolving 0.01 gram molecule = 1.22 grams of salicylic aldehyde in 10 cc. N sodium hydroxide solution and adding definite amounts of hydrogen peroxide of known strength (1 cc. = 0.0137 gram oxygen). When an amount (12 cc.) equivalent to slightly more than 0.01 molecule oxygen (11.7 cc.) was added, no unchanged salicylic aldehyde was precipitated on acidification. When 9.0 cc. were employed there was slight precipitation and a large precipitation when 6.0 cc. were taken. From the preceding results it may be justly assumed that the reaction takes place in the proportion of 1 molecule of aldehyde, 1 molecule of alkali and 1 molecule hydrogen peroxide.¹

It was found that while the formation of catechol from free salicylic aldehyde and hydrogen peroxide could be readily demonstrated when the two substances were boiled together, under a reflux condenser, the reaction was slow and did not take place with the smoothness characteristic of the oxidation

¹ In the oxidation of nitro derivatives of *o*- and *p*-hydroxybenzaldehyde it is advisable to use at least 2 molecules of alkali.

of the salts. That this difference was not simply due to the sparing solubility of the free aldehyde was proved by carrying out similar experiments in acetone and in alcoholic solution. When the materials were allowed to stand at room temperature even for many hours no formation of catechol was detected.

Preparation of Catechol from Salicylic Aldehyde.—An almost theoretical yield of catechol may be obtained from salicylic aldehyde by adopting the following method which is typical of all the experiments subsequently made in which other aldehydes were oxidized.

Salicylic aldehyde (1 mol.) is dissolved in normal caustic soda solution (1 mol.) and dilute hydrogen peroxide (2.5–3 per cent.) equivalent to 1.25 molecules added in one portion. The liquid changes in color from yellow to light brown and soon becomes hot. The mixture is allowed to stand until cool and is then acidified with a little sulphuric acid and sodium bicarbonate is added in slight excess. The liquid is then extracted with ether. On evaporation of the ether a crystalline residue of catechol remains behind which is readily purified by a single recrystallization from benzene. The substance melted at 104° and was identical in every respect with catechol of other origin. Analysis:

	Calculated for $C_6H_6O_2$.	Found.
C	65.28	65.45
H	5.51	5.45

5-Chlor-2-hydroxybenzaldehyde.—This substance was prepared according to Biltz and Stepf's¹ directions by the limited chlorination of salicylic aldehyde. On oxidation of the sodium salt, chlorcatechol was obtained in good yield.

3,5-Dichlor-2-hydroxybenzaldehyde.—The prolonged chlorination of salicylic aldehyde dissolved in glacial acetic acid gave a good yield of dichlorsalicylic aldehyde. The substance melted at 95° – 96° and crystallized from slightly diluted acetic acid in large prisms which retain a very faint yellow color. These

¹ Ber. d. chem. Ges., **37**, 4022.

observations accord with those of Biltz and Stepf and are not in agreement with the results of earlier investigators.

On oxidation an excellent yield of 3,5-dichlorcatechol was obtained. The substance is only moderately soluble in cold water; very soluble in hot water. It crystallizes in long, flat, colorless prisms, melting sharply at 83° – 84° . Its aqueous solutions instantly reduce ammoniacal silver nitrate and give with ferric chloride a clear green coloration which becomes violet on addition of sodium bicarbonate. Analysis:

0.2270 gram gave 0.3610 gram AgCl =	39.28 per cent. Cl
$C_6H_4O_2Cl_2$ requires	39.14 per cent. Cl

5-Brom-2-hydroxybenzaldehyde.—This substance was prepared by the bromination of salicylic aldehyde in glacial acetic acid solution. On oxidation it gave a substance exhibiting all the characteristics of a catechol derivative. The substance crystallizes from boiling petroleum, in which it is only slightly soluble, in thick prisms melting at 86° – 87° . It is much more soluble in benzene and very soluble in water and alcohol. Its aqueous solutions instantly reduce ammoniacal silver nitrate in the cold and give a clear green coloration with ferric chloride, turning violet on addition of sodium bicarbonate. Analysis:

0.1052 gram gave 0.1042 gram AgBr =	42.15 per cent. Br
$C_6H_5O_2Br$ requires	42.32 per cent. Br

3,5-Dibrom-2-hydroxybenzaldehyde.—Salicylic aldehyde was brominated in acetic acid solution with rather more than 2 molecules of bromine. The recrystallized aldehyde melted at 83° – 85° and on oxidation readily gave a catechol derivative, although a not inconsiderable amount of unoxidized aldehyde remained. The ethereal extract from the acidified and filtered solution was evaporated to dryness and then stirred with a little cold water and filtered from a small insoluble residue. The filtrate on concentration slowly crystallized, but the melting point of the crystals was not sharp. It was found difficult to recrystallize the substance, which, however, readily gave the characteristic reaction for a catechol derivative;

accordingly it was treated with an excess of bromine and thus converted into the beautifully crystalline tetrabromcatechol, melting at 189° , already described by Hlasiwetz.¹

3-Nitro-2-hydroxybenzaldehyde.—The sodium salt of this substance (1 mol.) was mixed with hydrogen peroxide (1.5 mols.) and normal caustic soda was added by degrees until the solution acquired a permanent purple color. On acidifying the solution a considerable amount of unchanged aldehyde was precipitated. 3-Nitrocatechol was obtained by extracting the filtrate with ether and recrystallizing from water containing a little alcohol.

5-Nitro-2-hydroxybenzaldehyde.—This substance was oxidized in the same manner as in the preceding case but the yield of 5-nitrocatechol was materially better (about 70 per cent.). The substance was crystallized from a very little water, in which it is very soluble, and melted at 174° . This result differs but slightly from the observations of Bamberger and Czerki ($175^{\circ}.5$) and is materially higher than the melting points recorded by Benedikt and other observers.³

p-Hydroxybenzaldehyde.—The salts of this substance upon oxidation with hydrogen peroxide exhibited precisely the same phenomena as those observed in the case of salicylic aldehyde and the reaction was carried out in the same manner as in the case of the latter substance. The yield of quinol approximated the theoretical amount. It was purified by crystallization from benzene or from water. The substance melted sharply at 170° . Analysis:

	Calculated for $C_6H_6O_2$.	Found.
C	65.40	65.45
H	5.61	5.45

Molecular weight by freezing point method, acetic acid for solvent:

Found, 114.3; calculated, 110.

3,5-Dichlor-4-hydroxybenzaldehyde.—*p*-Hydroxybenzaldehyde was chlorinated in glacial acetic acid according to the direc-

¹ Ann. Chem. (Liebig), **142**, 251.

² J. prakt. Chem., [2] **68**, 480.

³ Ber. d. chem. Ges., **11**, 362; Mameli, Atti. R. Accad. Lincei, [5] **14**, II, 510.

tions of Auwers and Reis¹ and the product purified by crystallization from alcohol. The oxidation of the potassium salt with hydrogen peroxide took place smoothly with an excellent yield of 2,6-dichlorquinol. Crystallized from benzene or water, the substance was obtained in the form of needles melting at 163°–164°, agreeing with Kehrman and Tiesler's observations.² On warming the substance with ferric chloride solution, 2,6-dichlorquinone, melting at 120°, was obtained.

3-Nitro-4-hydroxybenzaldehyde.—*p*-Hydroxybenzaldehyde was nitrated in glacial acetic acid with slightly more than the theoretical amount of concentrated nitric acid according to Paal's method.³ The crude nitro derivative was purified by crystallization from alcohol. It was found that the salts of this substance were practically unattacked on treatment with hydrogen peroxide either in the cold or at the boiling temperature. The use of Caro's acid proved no more successful.

3-Brom-4-hydroxybenzaldehyde.—*p*-Hydroxybenzaldehyde was brominated in chloroform solution according to Paal's method⁴ and the product crystallized from boiling water. The sodium salt was readily oxidized with hydrogen peroxide, giving a good yield (60–70 per cent.) of bromquinol. The crude product melted at 110° but on recrystallization from a mixture of benzene and ligroin, the melting point rose to 113°–115°. Saraw⁵ gives 110°–111° as the melting point of this substance.

3,5-Dibrom-4-hydroxybenzaldehyde.—This aldehyde was obtained according to Paal's⁶ directions and crystallized in long needles melting at 180°–181°. It was found advisable to use 2 molecules of caustic soda, in place of 1 molecule, for the oxidation of this substance with hydrogen peroxide. The reaction took place readily, with the usual color and temperature changes. At the close of the reaction, on acidifying the solution, a precipitate consisting of a mixture of unchanged

¹ Ber. d. chem. Ges., **29**, 2356.

² J. prakt. Chem., [2] **40**, 481.

³ Ber. d. chem. Ges., **28**, 2413.

⁴ *Ibid.*, p. 2409.

⁵ Ann. Chem. (Liebig), **209**, 105.

⁶ *Loc. cit.*, p. 2410.

aldehyde and dibromquinol was obtained. The filtrate on extraction with ether gave a small yield of dibromquinol which crystallized from water in well-formed platelets melting at 163° – 164° . The substance was doubtless identical with the 2,6-dibromquinol obtained by Ling¹ by the reduction of dibromquinone with sulphurous acid.

3,5-Diiod-4-hydroxybenzaldehyde.—This substance was prepared by the action of iodine and iodic acid upon *p*-hydroxybenzaldehyde.² No appreciable amount of diiodoquinol was obtained on treatment of its sodium salt with hydrogen peroxide.

2,4-Dihydroxybenzaldehyde.—One molecular proportion of caustic soda was used for the oxidation of this substance. The reaction with hydrogen peroxide was fairly vigorous but a considerable amount of aldehyde remained unoxidized and was removed by extracting the acidified solution with chloroform. On shaking with ether an extract was obtained which readily gave the reactions for hydroxyquinol, but the product was not pure. It was further identified by conversion into tribromhydroxyquinol by means of bromine. The product was crystallized from alcohol and from chloroform and melted at 206° – 207° , in agreement with the observations of Barth and Schroeder.³

3,4-Dihydroxybenzaldehyde.—On oxidation of the monopotassium salt of this aldehyde with hydrogen peroxide the substance behaved in precisely the same manner as the preceding substance, a small quantity of hydroxyquinol being obtained.

Vanillin.—An almost theoretical yield of the methyl ether of hydroxyhydroquinone was obtained by the oxidation of the sodium salt of vanillin with hydrogen peroxide. The substance was crystallized from benzene and melted at 82° – 83° . This substance was previously obtained by Will⁴ by the reduction of the methyl ether of 2-hydroxyquinone with sulphurous acid.

5-Nitrovanillin.—As in the case of the similarly constituted

¹ Trans. Chem. Soc., **61**, 562.

² Ber. d. chem. Ges., **28**, 2412.

³ Monats. Chem., **5**, 593.

⁴ Ber. d. chem. Ges., **21**, 606.

m-nitro-*p*-hydroxybenzaldehyde, no formation of a quinol derivative could be detected upon oxidizing this substance with hydrogen peroxide.

2-Nitrovanillin.—This substance was prepared according to the method of Pschorr and Sumuleanu¹ by the nitration of acetylvanillin and saponification of the resulting nitro derivatives with caustic soda. The product was crystallized from boiling water and melted at 135°. On oxidation of the potassium salt with hydrogen peroxide (1.5 mols.) and caustic potash (2 mols.) an excellent yield of 2-nitro-3-methoxyquinol was obtained. The substance crystallizes from benzene in large deep-red prisms melting at 86°.5–87°.5. Analysis:

0.2555 gram gave 0.01904 gram N = 7.45 per cent. N
C ₇ H ₇ O ₅ N requires 7.57 per cent. N

5-Bromvanillin.—A bromvanillin was obtained by Carles and by Tiemann and Haarmann² by the bromination of aqueous or alcoholic solutions of vanillin and is described as a yellowish substance melting at 160°–161°, sparingly soluble in cold water. The constitution of the substance was not determined. It was found that bromination in aqueous solution, even with the addition of potassium acetate, was very undesirable owing to the formation of deeply pigmented impurities. The following conditions were found advantageous for the preparation of bromvanillin.

Vanillin (15.2 grams) is dissolved in warm glacial acetic acid (30 cc.) and to the solution, while cooled under the tap, bromine (5.4 cc.) dissolved in acetic acid (20 cc.) is added fairly rapidly with shaking. Crystallization occurs almost immediately and water is then added and the crystals are filtered off and crystallized from boiling 95 per cent. alcohol. Bromvanillin separates in large cubic crystals which when freshly recrystallized are perfectly colorless but acquire a slight yellowish tinge on standing. The yield of recrystallized substance is 20–21 grams. The substance melts at 163°–164° and is sparingly soluble in cold but readily in hot alcohol. It is practically insoluble in hot or cold water, sparingly soluble

¹ Ber. d. chem. Ges., **32**, 3408.

² *Ibid.*, **7**, 614.

in ether or benzene. Bromvanillin dissolves in aqueous caustic potash to give a light yellowish solution of the potassium salt. Bromvanillin was methylated in the usual manner by warming the substance with a considerable excess of dimethyl sulphate and a 10 per cent. solution of caustic potash. The product, 5-bromveratric aldehyde, separates in the form of an oil, insoluble in alkali, which quickly becomes solid on cooling. It is readily recrystallized from 80 per cent. alcohol and separates in the form of white masses of felted needles which melt sharply at 65° – 66° .

5-Bromveratric aldehyde was oxidized by boiling the substance for about one hour with slightly more than the theoretical amount of chromic acid dissolved in 5 parts of glacial acetic acid. On dilution with water, the precipitated acid was filtered off and dried and then boiled with petroleum ether to remove any unchanged aldehyde. The 5-bromveratric acid remaining was crystallized from dilute alcohol and then converted into the methyl ester by means of methyl alcohol and hydrochloric acid in the usual way. The product, after crystallization from petroleum, melted sharply at 69° – 70° and was identical with the 5-bromveratric acid methyl ester prepared by Zincke and Franke.¹

5-Bromvanillin (4.6 grams) was converted into the potassium salt by warming with 21 cc. N caustic potash solution and then adding a 30 per cent. excess of dilute hydrogen peroxide. The liquid at once became dark purple and heat was evolved. After gently warming for a few minutes, the products of the reaction were isolated in the usual way. The ether extract gave slightly more than 2.0 grams of a pigmented crystalline residue, which after crystallization from boiling water gave a good yield of pure substance. There can be little doubt that the compound is 5-brom-3-methoxyquinol. The substance is colorless when pure and crystallizes from water in thick prisms or needles, melting at 141° – 143° . It is only moderately soluble in cold water, easily in hot, easily soluble in hot benzene, almost insoluble in petroleum. The aqueous solution reduces

¹ Ann. Chem. (Liebig), **293**, 183.

alkaline silver solutions and Fehling's solution in the cold. Analysis:

0.2426 gram gave 0.2062 gram AgBr = 36.2 per cent. Br
 $C_7H_7O_3Br$ requires 36.5 per cent. Br

The Oxidation of Derivatives of Acetophenone.

The following ketones were oxidized by warming their ammonium or sodium salts with a 25 per cent. excess above the theoretical amount (1 mol.) of hydrogen peroxide. The reaction does not take place as easily as in the case of the corresponding aldehydes and the yields, particularly in the case of the dihydroxyketones, are smaller.

Oxidation of p-Hydroxyacetophenone.—The ketone was gently boiled for a few minutes with a slight excess of ammonia and hydrogen peroxide. The sodium salt was also used successfully. On acidifying and allowing to stand, a considerable amount of unchanged ketone crystallized out. The filtrate was extracted with ether and the crude quinol recrystallized from benzene. It melted at 170° . Yield, 40–50 per cent. Analysis:

	Calculated for $C_8H_8O_2$.	Found.
C	65.34	65.45
H	5.56	5.45

o-Hydroxyacetophenone.—This substance was prepared by reducing *o*-nitroacetophenone, separated according to Camp's¹ directions from the products of nitration of acetophenone, and subsequently heating the solution of the diazotized base. The amount of pure substance obtained was small, but it was easy to identify catechol as a product of the oxidation of its sodium salt with hydrogen peroxide by proceeding in the same manner as in the case of the preceding para derivative.

2,4-Dihydroxyacetophenone (Resacetophenone).—The sodium salt of this substance was oxidized in the usual way, the solution being heated slowly to the boiling point, but much un-

¹ Archiv. Pharm., 240, 1 (1902).

changed ketone was precipitated on acidification. On extraction with ether and treatment of the ethereal residue with a little cold water, a solution was obtained which gave the characteristic reactions for hydroxyhydroquinone. Ferric chloride gave an olive-greenish coloration, becoming blue on addition of a trace of sodium carbonate and wine-red when an excess of the latter salt was added. The yield of hydroxyhydroquinone was very poor. On treatment with bromine, as in the case of the product from 2,4-dihydroxybenzaldehyde, tribromhydroxyhydroquinone was obtained.

Monomethyl and Monoethyl Ethers of 2,4-Dihydroxyacetophenone.—Qualitative experiments with the sodium salts of these substances showed that both of them were oxidized by hydrogen peroxide, with formation of small quantities of hydroxyhydroquinone methyl and ethyl ether, respectively

2,5-Dihydroxyacetophenone.—The behavior of the sodium salt of this substance on oxidation with hydrogen peroxide was similar to that of 2,4-dihydroxyacetophenone. Much unchanged substance, together with a little hydroxyquinol, were obtained.

The Oxidation of p-Hydroxyphenylethyl Ketone.

This ketone was obtained in small yield by the condensation of phenol and propionic acid by means of zinc chloride according to the directions of Goldzweig and Kaiser.¹ The product was repeatedly recrystallized from water and melted sharply at 148°–149°. The potassium salt was oxidized in the usual way by dissolving 0.01 gram molecule of the substance (= 1.50 grams) in 10 cc. of normal potash solution and adding about 0.02 gram molecule of hydrogen peroxide. No appreciable action took place in the cold, so the mixture was gently boiled for about fifteen minutes. The liquid was then acidified and allowed to stand overnight so as to make the precipitation of unchanged ketone as complete as possible. The filtrate on extraction with ether gave a minute quantity of quinol (0.15 gram). It was characterized by its melting point (169°) and the usual reactions.

¹ J. prakt. Chem., [2] 53, 86.

Oxidation of Derivatives of m-Hydroxybenzoic Acid.

The oxidation with hydrogen peroxide of the salts of the halogen and nitro derivatives of *m*-hydroxybenzoic acid, referred to in the table on p. 479, gave uniformly negative results. The only derivative of *m*-hydroxybenzaldehyde which gave any trace of a resorcin derivative was 3-hydroxy-4-methoxybenzaldehyde (isovanillin). This substance, prepared by the action of methyl iodide upon the monopotassium salt of protocatechuic aldehyde, was converted into the potassium salt and then heated with excess (2 mols.) of hydrogen peroxide. No appreciable action took place in the cold, so the solution was gently boiled. On acidifying and allowing the solution to stand, much dark colored unchanged substance was precipitated. On extracting the filtrate with ether, after neutralizing with sodium bicarbonate, a very small quantity of crystalline substance was obtained which gave certain reactions which indicated the possibility of the presence of a polyhydric phenol. The quantity was too small to satisfactorily purify but the following facts were ascertained: The substance was very soluble in water, alcohol and ether, but insoluble in petroleum ether. The aqueous solutions gave a deep violet red coloration with ferric chloride and reduced ammoniacal silver nitrate and Fehling's solution in the cold.

Oxidation of o-Hydroxybenzaldehyde with Various Reagents.

Sodium and barium peroxides were both found to bring about the formation of catechol from salicylic aldehyde. In the case of sodium peroxide, the powdered substance (1.5 mols.) was added in small portions to an ice-cooled mixture of salicylic aldehyde (1 mol.) with ten parts of water. The substance was subsequently warmed to 60°. On acidifying and extracting with ether, catechol was obtained in large quantity. The reaction in the case of barium peroxide was effected by heating the mixture of peroxide, aldehyde and water under a reflux condenser. A similar method was adopted in the case of the peroxide of manganese and lead but with these reagents no catechol was formed.

Benzoylhydrogen peroxide was prepared by Baeyer's method by the action of sodium ethylate (1 mol.) on benzoyl superoxide (1 mol.) in ethereal solution. The white precipitate of the sodium derivative of benzoylhydrogen peroxide was dissolved in water and the solution so obtained added directly to a solution of the sodium salt of salicylic aldehyde. The solution at once became darker and heat was evolved. On acidifying, a large precipitate of benzoic acid was obtained which melted at 121° after recrystallization from water. The filtrate, on extraction with ether, gave an abundant yield of catechol. Neither benzoylcatechol nor benzoylformic acid could be detected.

The action of Caro's acid upon salicylic aldehyde was investigated under precisely the same conditions as those adopted by Baeyer and Villiger in the preparation of the superoxide of benzaldehyde.¹ No superoxide of salicylic aldehyde could be isolated, but on dilution and extraction with ether catechol was obtained.

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[Contributions from the Sheffield Laboratory of Yale University.]

CLXXIV.—RESEARCHES ON HALOGENAMINO ACIDS:
IODINE DERIVATIVES OF ORTHOTOLUIDINE. THE
3-IODAMINOBENZOIC ACIDS.²

[SEVENTH PAPER.]

BY HENRY L. WHEELER AND LEONARD M. LIDDLE.

Iodine acting on *p*-toluidine has been shown by us to yield two iodtoluidines, 1-methyl-3-iod-4-aminobenzene and 1-methyl-3,5-diiod-4-aminobenzene.

We now find that when iodine is mixed with *o*-toluidine only one iodine derivative is formed and this mono derivative can be melted with iodine without further substitution taking place. There is therefore considerable difference in the capacity

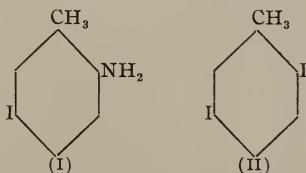
¹ Ber. d. chem. Ges., **33**, 2479.

² Part of a thesis presented by Leonard M. Liddle for the degree of Ph.D., Yale, 1909.

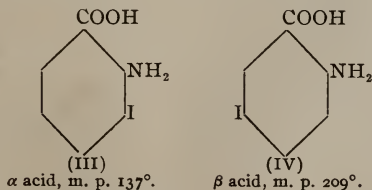
of these toluidines to take up iodine. A still greater tendency to take up iodine is shown in the case of *m*-toluidine. The compounds derived from this base will be described in a later paper.

The monoiod-*o*-toluidine, which is obtained smoothly and in excellent yield by mixing *o*-toluidine with iodine, proves to be 1-methyl-2-amino-5-iodbenzene (I). This substance has previously been prepared by Artmann¹ by an indirect method.

From this iod-*o*-toluidine we have prepared the new 2,5- or 3,6-diiodtoluene (II) by diazotizing and treating the solution with potassium iodide. We then found that this diiodtoluene is not identical with that prepared from diiod-*p*-toluidine.



Grothe² obtained three of the four theoretically possible mononitro derivatives of *m*-iodbenzoic acid by nitrating the acid. Two of these acids, his so-called α and β acids, he obtained in sufficient quantity to reduce to the corresponding iodamino acids. Both of these, he found, gave on further reduction *o*-aminobenzoic acid. One of these acids is therefore 2-amino-3-iodbenzoic acid (III) and the other must be 2-amino-5-iodbenzoic acid (IV). The question as to which is which was not decided.

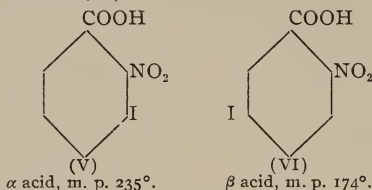


¹ Monats. Chem., 26, 1097 (1905).

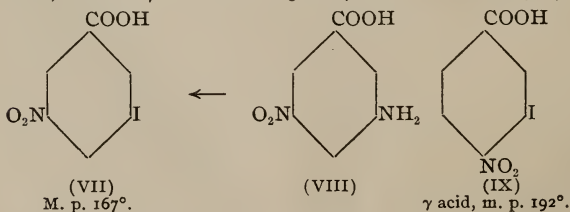
² J. prakt. Chem., [2] 18, 326 (1878).

We have found that when the acetyl derivative of 1-methyl-2-amino-5-iodbenzoic (I) from *o*-toluidine and iodine is oxidized with potassium permanganate and the product boiled with concentrated hydrochloric acid a good yield of 2-amino-5-iodbenzoic acid (IV) results. This acid melting at 209° proved to be identical with Grothe's β -iod-2-aminobenzoic acid.

It follows from this that his α -iodaminobenzoic acid, melting at 137° , is 3-iod-2-aminobenzoic acid (III). His α -nitroiodbenzoic acid, melting at 235° , is 2-nitro-3-iodbenzoic acid (V) and his β -nitroiodbenzoic acid, melting at 174° , is 2-nitro-5-iodbenzoic acid (VI).



In Beilstein's *Handbuch*¹ Grothe's γ -nitroiodbenzoic acid, melting at 192° , is listed as 3-iod-5-nitrobenzoic acid (VII) but like his other acids it is represented as subject to interrogation. We have prepared this 3-iod-5-nitrobenzoic acid from Hübner's² 3-amino-5-nitrobenzoic acid (VIII) by means of the diazo reaction. An iodonitrobenzoic acid, melting at 167° , was obtained which is not identical with the acid described by Grothe. Since this completes the list of the theoretically possible mononitro acids derived from *m*-iodbenzoic, Grothe's γ acid must be 3-iod-4-nitrobenzoic acid (IX).

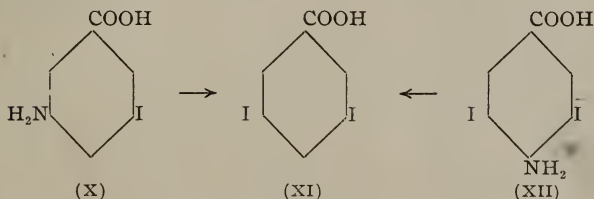


¹ [3] 2, 1244.

² Ann. Chem. (Liebig), 222, 81 (1884).

We have prepared 3-iod-5-aminobenzoic acid (X) by reducing 3-iod-5-nitrobenzoic acid. This completes the list of the four theoretically possible monaminobenzoic acids having an iodine atom in the meta position to the carboxyl group.

The diazotization of our 3-iod-5-aminobenzoic acid and subsequent treatment with potassium iodide gave 3,5-diiodobenzoic acid (XI), which proved to be identical with the acid obtained from Michael and Norton's¹ diiod-*p*-aminobenzoic acid (XII) on removing the amino group. This affords conclusive proof that the iodine atoms are in the 3,5-position in these compounds.



EXPERIMENTAL PART.

5-Iod-2-aminotoluene.—When *o*-toluidine and iodine, in molecular proportions, were mixed, heat was evolved and immediate substitution took place. In order to complete the reaction some ether, calcium carbonate, and a little water were added. The mixture was then warmed on the steam bath for a half hour, or until the iodine disappeared, the flask being attached to a return condenser. If the product was shaken out with ether and the ether evaporated the yield of crude product was over 90 per cent. of the theoretical, but the material was very dark. It was found that by distilling with steam a much better purification was effected. This removed all color and gave over 80 per cent. of the calculated amount of pure white solid. It is easily volatile in steam and it crystallizes in beautiful, large, colorless prisms from gasoline. It

¹ THIS JOURNAL, 1, 264 (1879).

melted at 90° – 91° . Artmann gives 91° – 92° . In all other respects our product agreed with Artmann's descriptions.

	Calculated for C_7H_8NI .	Found.
N	6.01	5.83

2,5-Diiodtoluene.—Nineteen grams of 5-iod-2-aminotoluene, 100 cc. of concentrated hydrochloric acid, and 300 cc. of water were mixed and diazotized in the cold with 8 grams of sodium nitrite in 40 cc. of water. The clear, filtered solution was treated with about 38 grams of potassium iodide in 75 cc. of water. This produced a bulky precipitate, which was allowed to stand and then warmed until nitrogen was evolved and the substance sank down to a black oil. The free iodine was removed with a little sodium bisulphite and the oil was extracted with ether and distilled in steam. It came over easily and solidified on standing. When washed with a little ether and pressed on paper it melted at 30° – 31° . It was very soluble in petroleum ether, ether, and hot alcohol but insoluble in water. When crystallized from strong alcohol, it gave long, colorless plates, which melted as before at 30° – 31° .

	Calculated for $C_7H_6I_2$.	Found.
I	73.83	73.86

The melting point of this diiodtoluene is near that of 2,3-diiodtoluene (31° – 32°). It differs notably from this compound in its volatility in steam, and when the substances were mixed the mixture immediately liquefied. The same result was produced on mixing with 3,5-diiodtoluene.

5-Iod-2-acettoluide, from 5-iod-2-aminotoluene and acetic anhydride, was difficultly soluble in water and separated in the form of fine needles. It is easily soluble in alcohol; from dilute alcohol it gave long, colorless needles melting to a clear oil at 169° .

	Calculated for $C_9H_{10}ONI$.	Found.
N	5.09	5.10

5-Iod-2-benztoluide, from the base and thiobenzoic acid, crystallized from alcohol in colorless needles, which melted to a clear oil at 184° . The material was insoluble in water.

	Calculated for $C_{14}H_{12}ONI$.	Found.
N	4.15	4.20

5-Iod-2-acetaminobenzoic Acid.—Six grams of 5-iod-2-acet-toluide were suspended in 250 cc. of hot water which contained 12 grams of magnesium sulphate. Steam was forced in while 10.5 grams of potassium permanganate in 1 per cent. solution were slowly added during the course of 12 hours. The excess was then reduced with alcohol and the manganese dioxide was filtered off. The filtrate was evaporated to about 150 cc. and cooled. Some unaltered 5-iod-2-acettoluide (2.5 grams) separated. When the filtrate from this was made acid with hydrochloric acid a flocculent precipitate was formed which weighed 3.15 grams, or 47 per cent. of the calculated. The acid formed hairlike needles from water, in which it was difficultly soluble. Alcohol and alkali dissolved it very easily. When crystallized from 50 per cent. alcohol it formed burrs of colorless needles which melted with decomposition and effervescence at 235° .

	Calculated for $C_9H_5O_3NI$.	Found.
N	4.59	4.58

5-Iod-2-aminobenzoic Acid.—Grothe's β -iod-2-aminobenzoic acid was easily obtained when the above acetamino acid was warmed with hydrochloric acid. When the acid had dissolved, the solution was evaporated to dryness and the residue was taken up in ammonia and precipitated by acetic acid. The precipitate formed twinned prisms from dilute alcohol and melted at 209° – 210° .

	Calculated for $C_7H_6O_2NI$.	Found.
N	5.32	5.39

3-Iod-5-nitrobenzoic Acid.—Hübner's 3,5-dinitrobenzoic acid¹ was reduced, according to his directions, to 3-amino-5-nitrobenzoic acid. Sixteen grams of this acid were dissolved in 100 grams of concentrated hydrochloric acid and 250 cc. of water. This solution was diazotized at 0° with 7.2 grams of

¹ *Loc. cit.*

sodium nitrite in 35 cc. of water, and then 55 grams of potassium iodide in 80 cc. of water were added. The mixture stood overnight and then was warmed. It was finally cooled in ice water and the crude acid which separated was found to weigh 18.1 grams, or 70 per cent. of the calculated. In another experiment 4 grams of nitramino acid gave 4.7 grams of iodnitro acid, 73 per cent. of the calculated. 3-Iod-5-nitrobenzoic acid dissolves in ammonia and is precipitated by acetic acid. It is not soluble in an excess of hydrochloric acid. It is readily soluble in alcohol and separates slowly in bunches of needles. It is difficultly soluble in cold water and only moderately soluble in hot, from which it crystallizes in long, slender needles. It has a straw-yellow color and melts to a yellow oil at 167° .

N	Calculated for $C_7H_4O_4NI$.	I.	Found. II.
	4.77	4.77	4.85

This acid has the peculiar property of melting under hot water when a few drops of alcohol are added. Its melting point, color, and its lack of solubility in water show that it is not Grothe's γ -nitro-*m*-iodbenzoic acid.

3-Iod-5-aminobenzoic Acid.—Eight grams of 3-iod-5-nitrobenzoic acid were dissolved in 100 cc. of concentrated ammonia and added to a solution of 49 grams of ferrous sulphate in 200 cc. of warm water. The flask was closed with a tube provided with a water trap and heated on the steam bath for four and one-half hours. The mixture was then filtered and a small portion of the filtrate was precipitated with hydrochloric acid. The precipitate which was formed dissolved immediately in an excess of acid. The reduction was therefore complete. The main portion was evaporated to a small volume and then precipitated with acetic acid. This gave a finely divided precipitate which weighed 6.2 grams, or 87 per cent. of the calculated. It crystallized in long, straw-yellow spikes from dilute alcohol and melted to a clear oil at 197° .

N	Calculated for $C_7H_6O_2NI$.	Found.
	5.32	5.42

This acid gives a difficultly soluble hydrochloride. It is soluble in acetic acid.

3,5-Diiodbenzoic Acid.—Five grams of 3-iod-5-aminobenzoic acid were suspended in 50 cc. of concentrated hydrochloric acid and 150 cc. of water. Very little dissolved but the whole was placed in a freezing mixture and treated with 2 grams of sodium nitrite in 14 cc. of water. The precipitate seemed to become thinner, then thicker. It consisted of needles and did not dissolve on the addition of 250 cc. more of ice water. The suspension stood an hour and was then treated with 13 grams of potassium iodide in 25 cc. of water. After two hours the mixture was warmed. The yellowish material which separated was found to weigh 6.9 grams. This is 97 per cent. of the calculated. When this substance was boiled with water and the solution cooled, nothing but a mere turbidity was observed, the material remaining insoluble. It was purified by dissolving in hot alcohol, in which it is readily soluble, and then pouring into a large volume of water. The precipitate was then crystallized from 95 per cent. alcohol. It formed small, oblong tables or prisms which melted to a red oil at 235° – 236° . The acid is precipitated from its solution in ammonia by acetic acid. It dissolves in benzene and crystallizes in wavy wisps of needles. From ether it separates in canoe-shaped, flat plates. When it was mixed with the 3,5-diiodbenzoic acid prepared from 3,5-diiod-4-aminobenzoic acid the melting point was not altered.

	Calculated for $C_7H_4O_2I_2$.	Found.
I	67.91	67.04

NEW HAVEN, CONN.,
May, 1909.

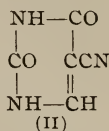
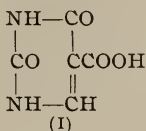
[Contributions from the Sheffield Laboratory of Yale University.]
CLXXV.—RESEARCHES ON PYRIMIDINES:
SYNTHESIS OF 5-CYANURACIL.

[FORTY-EIGHTH PAPER.]

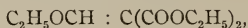
BY TREAT B. JOHNSON.

The present work was undertaken with the object of preparing some pyrimidines to be used for the syntheses of new

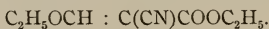
derivatives of thymine. I shall describe the preparation and properties of the nitrile of uracil-5-carboxylic acid (I), *viz.*, 5-cyanuracil (II), and some of its derivatives.



It has been shown in a previous paper from this laboratory¹ that diethyl ethoxymethylenemalonate,²



condenses smoothly with pseudothiureas, $\text{H}_2\text{NC}(\text{SR}) : \text{NH}$, in aqueous solution, in the presence of alkali, giving 2-alkyl-mercapto-5-carboxyl-6-oxypyrimidines. Uracil-5-carboxylic acid (I) is then obtained easily by hydrolysis of these mercaptopyrimidines with acids. It seemed very probable to the writer that 5-cyanuracil (II) might be synthesized in an analogous manner from ethyl ethoxymethylenecyanacetate,



DeBollemont³ has described several esters of this character, which he has prepared by condensation of orthoformic esters, $\text{CH}(\text{OR})_3$, with esters of cyanacetic acid in presence of acetic anhydride. He has also examined the behavior of several of them towards organic bases and shown that they react smoothly with formation of the corresponding amino derivatives,



The action of ureas, thioureas, pseudoureas, and pseudothioureas on these esters, however, has not been investigated.

Ethyl ethoxymethylenecyanacetate was prepared for my experiments according to the directions of deBollemont.⁴ I now find that pseudoethylthiourea condenses in alcoholic

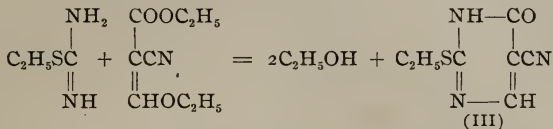
¹ THIS JOURNAL, **37**, 392 (1907).

² Claisen: Ann. Chem. (Liebig), **297**, 75 (1897).

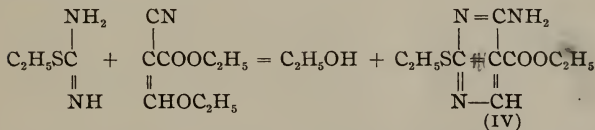
³ Compt. Rend., **128**, 1338; **129**, 5; Bull. Soc. Chim., [3] **25**, 18, 28, 39.

⁴ *Loc. cit.*

solution with this ester, in the presence of alkali, in two ways, giving a mixture of two mercaptopyrimidines. The main reaction is a condensation with the ester, similar to that with diethyl ethoxymethylenemalonate,¹ giving 2-ethyl-mercapto-5-cyan-6-oxypyrimidine (III). This condensation is represented by the following equation:



A part of the acrylic ester, however, reacts with the pseudothiourea, giving 2-ethylmercapto-5-carbethoxy-6-aminopyrimidine (IV), which has previously been described in a paper from this laboratory.²



This interesting observation suggests that other cyanides containing the grouping $\text{C}_2\text{H}_5\text{OCH} : \text{C} - \text{CN}$ will be found to condense with pseudothioureas, giving aminopyrimidines.

It is interesting to note here that ethyl acetylcyanacetate,



does not condense with pseudoethylthiourea to give a pyrimidine.³ On the other hand, it has been shown that the pseudoureas,⁴ $\text{H}_2\text{NC}(\text{OR}) : \text{NH}$, condense with ethyl cyanacetate, in presence of alkali, giving the corresponding 2-alkyl-oxy-4-amino-6-oxypyrimidines.⁵

¹ *Loc. cit.*

² Wheeler and Johns: *THIS JOURNAL*, **38**, 594.

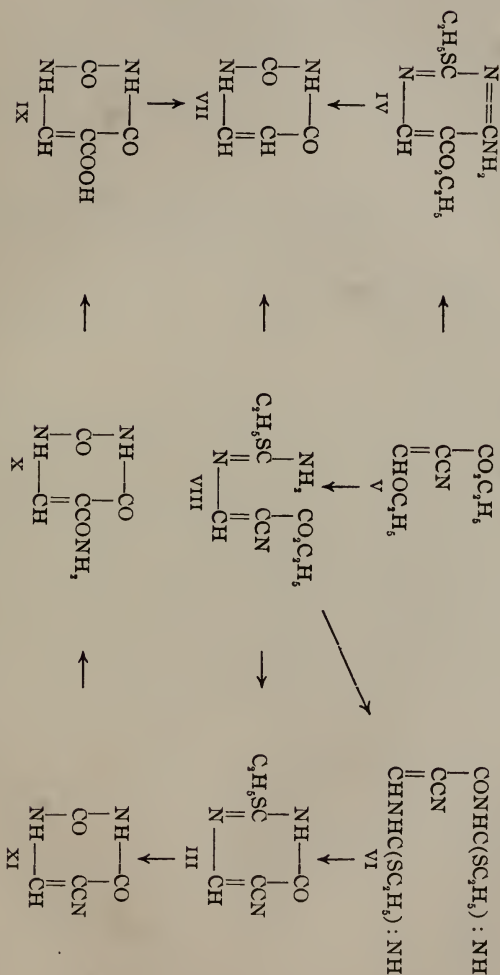
³ Wheeler: *THIS JOURNAL*, **28**, 358.

⁴ Stieglitz and McKee: *Ber. d. chem. Ges.*, **32**, 1494; **33**, 807, 1517; Stieglitz and Noble: *Ibid.*, **38**, 2243.

⁵ *Centrabl.*, **1904**, II, 631.

I also investigated the action of pseudoethylthiourea on ethyl ethoxymethylenecyanacetate (V) in alcohol containing no free alkali. When they were allowed to react under these conditions in molecular proportions, there was no evidence of the formation of 2-ethylmercapto-5-cyan-6-oxypyrimidine (III), and 2-ethylmercapto-5-carbethoxy-6-aminopyrimidine (IV) and ethyl α -cyan- β -pseudoethylthiourea-acrylate (VIII) were the only products of the reaction. If more than one molecular proportion of pseudoethylthiourea is used for the condensation the ethyl α -cyan- β -pseudoethylthiourea-acrylate that is formed then reacts with the excess of pseudothiourea, giving α -cyan- β -pseudoethylthiourea-acrylpseudoethylthiourea (VI).

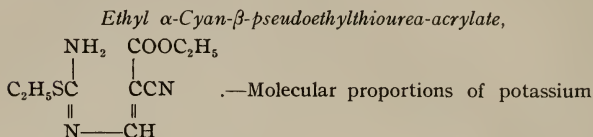
Ethyl α -cyan- β -pseudoethylthiourea-acrylate (VIII) and α -cyan- β -pseudoethylthiourea-acrylpseudoethylthiourea (VI) are both converted quantitatively into 2-ethylmercapto-5-cyan-6-oxypyrimidine (III) when warmed with alkali. A quantitative yield of 5-cyanuracil (XI) is then obtained by hydrolysis of this mercaptopyrimidine, in alcohol, with sulphuric acid. Attempts to hydrolyze this mercaptopyrimidine (III) smoothly to 5-cyanuracil, in aqueous solution, were unsuccessful. The nitrile group slowly undergoes hydrolysis under these conditions, giving a mixture of 5-cyanuracil (XI) and uracil-5-carboxamide (X). These are both converted quantitatively into uracil-5-carboxylic acid (IX) and finally into uracil (VII) by long digestion with concentrated hydrochloric acid. These various transformations are represented by the following formulas:



EXPERIMENTAL PART.

Ethyl Ethoxymethylenecyanacetate,
 $C_2H_5OCH : C(CN)COOC_2H_5$.—This ester was prepared according to the directions given by de Bollemont.¹ It melts at 52° – 53° and is insoluble in water but very soluble in alcohol, ether, and benzene.

Condensation of Ethyl Ethoxymethylenecyanacetate with One Molecular Proportion of Pseudoethylthiourea in Alcohol.

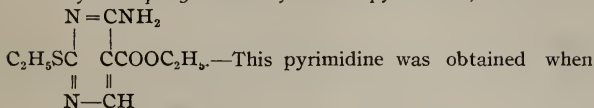


hydroxide (0.45 gram) and the hydrobromide of pseudoethylthiourea (1.4 grams) were dissolved separately in 7 cc. of 95 per cent. alcohol, the solutions cooled to 0° , and combined. The undissolved potassium bromide was then separated quickly by filtration and 1.2 grams of ethyl ethoxymethylenecyanacetate added to the cold alcohol solution of pseudoethylthiourea. The ester dissolved at once and within 1–2 minutes a yellow, crystalline substance separated. After standing a few minutes this was filtered off, washed thoroughly with ether, and the ether washings saved (see below). The substance obtained here, insoluble in ether, was the ethyl acrylate represented above and melted without further purification at 120° – 125° . The ester is soluble in alcohol, insoluble in cold water and ether, and crystallizes from benzene in tufts of yellow distorted needles melting at 130° with slight effervescence. It separates from a hot aqueous solution as an oil, which finally crystallizes in colorless needles melting at the same temperature. Nitrogen (Kjeldahl):

	Calculated for $C_9H_{13}O_2N_3S$.	Found.
N	18.50	18.7

¹ *Loc. cit.*

2-Ethylmercapto-5-carbethoxy-6-aminopyrimidine,



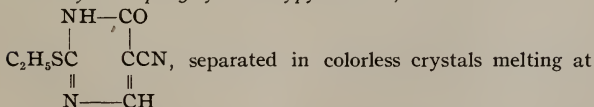
the ether solution described above was allowed to evaporate. It was insoluble in cold, dilute sodium hydroxide solution but soluble in hydrochloric acid, and crystallized from 95 per cent. alcohol in rectangular plates melting at 102°–103° to a clear oil with no effervescence. This same pyrimidine has previously been described by Wheeler and Johns.¹ A mixture of my derivative and their pyrimidine melted at 102°. Nitrogen (Kjeldahl):

	Calculated for $\text{C}_9\text{H}_{13}\text{O}_2\text{N}_3\text{S}$.	Found.
N	18.50	18.6

The comparative yields of the above acrylic ester and this 6-aminopyrimidine were irregular, but the ester was always the chief product of the reaction. They were apparently the only compounds formed under the conditions employed.

Action of Alkali on Ethyl α -Cyan- β -pseudoethylthiourea-acrylate.—This ester is not decomposed by cold, dilute sodium hydroxide solution. On the other hand, when warmed with alkali it immediately dissolved, giving the sodium salt of 2-ethylmercapto-5-cyan-6-oxypyrimidine. When the alkaline solution was acidified with hydrochloric acid,

2-Ethylmercapto-5-cyan-6-oxypyrimidine,



218°–20° to an oil. It crystallizes from hot water in prisms, which melt at 222° to a clear oil without effervescence. The pyrimidine gives a strong test for uracil when treated with bromine water and barium hydroxide solution.² Nitrogen determinations (Kjeldahl):

¹ *Loc. cit.*

² Wheeler and Johnson: *J. Biol. Chem.*, **3**, 183 (1907).

	Calculated for $C_7H_7ON_3S$.	I.	Found. II.
N	23.22	23.0	23.15

This pyrimidine and 2-ethylmercapto-5-carbethoxy-6-aminopyrimidine are the only products of the reaction when pseudoethylthiourea is condensed with ethyl ethoxymethylenecyanacetate in alcohol in the presence of an excess of alkali.

Condensation of Ethyl Ethoxymethylenecyanacetate with More than One Molecular Proportion of Pseudoethylthiourea in Alcohol.

An alcoholic solution of pseudoethylthiourea was prepared by dissolving 20 grams of the hydrobromide of pseudoethylthiourea (1.7 mols.) in 70 cc. of absolute alcohol and then adding, at 0° , a solution of 6.1 grams of potassium hydroxide (1.7 mols.) in 30 cc. of 95 per cent. alcohol. After filtering from potassium bromide, 10.7 grams of ethyl ethoxymethylene-cyanacetate (1 mol.) were added to the pseudourea solution at once when there was an immediate reaction and a thick mush of crystalline material was obtained. A portion of this material was filtered off and washed with ether. It then melted at 128° – 130° . This insoluble substance was identified as ethyl α -cyan- β -pseudoethylthiourea-acrylate, which was obtained in my previous condensation (see above). On evaporating the ether solution I obtained 2-ethylmercapto-5-carbethoxy-6-aminopyrimidine¹ which was identified by its melting point, 102° – 103° .

The main portion of the reaction mixture, however, was allowed to stand, at ordinary temperature, for about 2–3 hours, when, to my surprise, practically all of the acrylic ester, with the exception of about 1–2 grams, had dissolved. The solution was then filtered, concentrated on the steam bath, and cooled when I obtained about 12–13 grams of crystalline material. This was washed with ether to remove any 2-ethylmercapto-5-carbethoxy-6-aminopyrimidine, and then triturated with cold, dilute sodium hydroxide solution. I obtained 10.5 grams of a crystalline substance insoluble in the alkaline solution. It

¹ Wheeler and Johns: *Loc. cit.*

was soluble in hot water and alcohol and crystallized from hot water in well-developed prisms which melted at 164° – 165° with effervescence. A nitrogen determination agreed with the calculated value for α -cyan- β -pseudoethylthiourea-acrylpseudoethylthiourea, $\text{NH}_2\text{C}(\text{SC}_2\text{H}_5) : \text{NCH} : \text{C}(\text{CN})\text{CO.N} : \text{C}(\text{SC}_2\text{H}_5)\text{NH}_2$.

	Calculated for $\text{C}_{10}\text{H}_{15}\text{ON}_5\text{S}_2$.	Found.
N	24.56	24.43

When the sodium hydroxide solution (above) was carefully acidified with hydrochloric acid, 2-ethylmercapto-5-cyan-6-oxypyrimidine separated. It crystallized in prisms melting at 222° to an oil. Analysis (Kjeldahl):

	Calculated for $\text{C}_7\text{H}_7\text{ON}_3\text{S}$.	Found.
N	23.22	23.0

Action of Alkali on α -Cyan- β -pseudoethylthiourea-acrylpseudoethylthiourea.

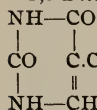
About 1.5 grams of this compound were warmed with 10 cc. of a 10 per cent. aqueous solution of sodium hydroxide for a few minutes. Ethyl mercaptan was evolved and the compound dissolved, giving a clear solution. When this was acidified with hydrochloric acid 2-ethylmercapto-5-cyan-6-oxypyrimidine separated in prisms melting at 220° – 222° . Analysis (Kjeldahl):

	Calculated for $\text{C}_7\text{H}_7\text{ON}_3\text{S}$.	Found.
N	23.22	23.16

Behavior with Hydrochloric Acid.—One gram of α -cyan- β -pseudoethylthiourea-acrylpseudoethylthiourea was dissolved in about 40–50 cc. of concentrated hydrochloric acid and the solution evaporated to dryness. I obtained practically a quantitative yield of 5-cyanuracil (see below) which melted without purification at 291° – 293° . After one crystallization from water it melted at 293° – 295° and a nitrogen determination (Kjeldahl) gave:

	Calculated for $\text{C}_5\text{H}_3\text{O}_2\text{N}_3$.	Found.
N	30.6	30.2

2,6-Dioxy-5-cyanpyrimidine (5-Cyanuracil),

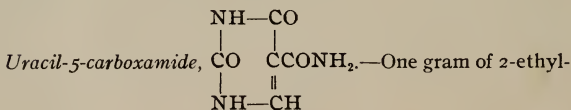


A quantitative yield of this pyrimidine was also obtained by hydrolysis of 2-ethylmercapto-5-cyan-6-oxypyrimidine with sulphuric acid as follows: 0.7 gram of the mercaptopyrimidine was dissolved in a mixture of 30 cc. of alcohol and 3 cc. of concentrated sulphuric acid and the solution boiled until the evolution of ethyl mercaptan ceased. The 5-cyanpyrimidine separated in hard, granular crystals melting at 291° – 292° . It is difficultly soluble in cold alcohol and crystallizes from hot water in prisms which melt at 295° with decomposition. Analysis (Kjeldahl):

	Calculated for $\text{C}_4\text{H}_3\text{O}_2\text{N}_3$.	I.	Found.
N	30.6	30.1	30.55

When this pyrimidine was digested with concentrated hydrochloric acid for several hours it was converted quantitatively into uracil. Analysis (Kjeldahl):

	Calculated for $\text{C}_4\text{H}_4\text{O}_2\text{N}_2$.	Found.
N	25.00	24.6



mercapto-5-cyan-6-oxypyrimidine was dissolved in 50 cc. of concentrated hydrochloric acid and the solution evaporated to dryness on the steam bath. The crystalline material which was obtained was then dissolved in hot water and the solution cooled slowly, when this pyrimidine separated in small prisms. It is difficultly soluble in cold water and does not melt below 300° . It gives a strong test for uracil when treated with bromine water and barium hydroxide. After heating for 5 hours at 100° – 110° a nitrogen determination (Kjeldahl) gave:

	Calculated for $\text{C}_5\text{H}_6\text{O}_3\text{N}_3$.	Found.
N	27.00	26.80

This amide was converted quantitatively into uracil when digested with concentrated hydrochloric acid.

The aqueous mother liquor (above), after being filtered from uracil-5-carboxamide, was concentrated to a small volume and cooled, when the characteristic prisms of 5-cyanuracil separated. After two crystallizations from hot water it melted at 293° – 295° . Analysis (Kjeldahl):

	Calculated for $C_6H_5O_2N_5$.	Found.
N	30.6	30.1

NEW HAVEN, CONN.,
July, 1909.

[Contribution from the Chemical Laboratory of the University of Cincinnati.]

THE PREPARATION OF HYDROXAMIC ACIDS FROM HYDROXYLAMINE SALTS OF ORGANIC ACIDS.

BY LAUDER WILLIAM JONES AND RALPH OESPER.

A survey of the various methods which have been employed in the synthesis of hydroxamic acids will show that almost every one of them has its counterpart in some process used to obtain acid amides. The amides are frequently made by heating ammonium salts; it is singular, therefore, that this method, very generally successful in the making of amides, has not led to a similar procedure for the direct preparation of hydroxamic acids from hydroxylamine salts.¹

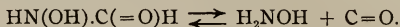
In the course of some experiments with hydroxylamine formate, $HC(=O).ONH_3OH$, it was observed that a solution of this salt in acidulated water gave no color reaction with ferric chloride. When, however, the salt had been kept for several weeks, or had been heated for a few minutes to its melting point (76°), and was subsequently dissolved in water, the addition of an acidulated solution of ferric chloride caused an intense purple color identical with that produced when a solution of formhydroxamic acid was treated with ferric chloride under similar conditions. It was evident that heat

¹ Ssabanejeff: J. russ. physik. chem. Ges., **31**, 377; Centralb., **1899**, II, 33. This author mentions incidentally that the hydroxylamine salt of succinamic acid, $H_2N.CO.C_2H_4.CO.ONH_3OH$, passed into the corresponding hydroxamic acid when it had been kept for a long time or had been heated to its boiling point.

had accelerated the change of the hydroxylamine salt into formhydroxamic acid, a transformation which proceeded with measurable velocity at ordinary room temperature.

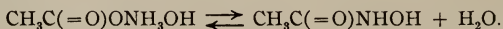


But unfortunately, the ease with which formhydroxamic acid dissociates into free hydroxylamine and carbon monoxide made it impracticable to carry out this reaction at temperatures even a few degrees above the melting point of the formate without causing considerable or total destruction of the hydroxamic acid expected:¹



That this reaction would prove to be reversible seemed quite plausible in view of the abundant analogy furnished by the many reversible reactions known to occur when carbon monoxide and various reagents interact.² To establish the correctness of this conclusion, a stream of carbon monoxide was passed through free hydroxylamine for several hours. A product resulted which, with ferric chloride, gave the usual test for hydroxamic acid.

To try the new method of making hydroxamic acids under more favorable conditions, the use of hydroxylamine acetate seemed more promising than the formate; but in this case also, the hydroxamic acid was found to undergo decomposition even below 100°. Nevertheless, at a temperature of 90°, a fairly successful synthesis of acethydroxamic acid was effected.



This reaction is undoubtedly reversible, and would reach a condition of equilibrium similar to that observed by Menshutkin³ in the case of ammonium acetate and acetamide, were it not for the complication that both acethydroxamic acid and hydroxylamine acetate dissociate slowly in other ways, with the result that at 90°, with a two-gram sample,

¹ Jones: *THIS JOURNAL*, **20**, 29; Biddle: *Ann. Chem. (Liebig)*, **310**, 14.

² DeLambelly: *D. R. P.* 78573 ($\text{NH}_2 + \text{CO}$); Loeb: *Z. Elek. Chem.*, **11**, 745 ($\text{CO} + \text{H}_2\text{O}$); **12**, 282 ($\text{CO} + \text{H}_2$).

³ Menshutkin: *J. prakt. Chem.*, [2] **29**, 422.

the amount of hydroxamic acid apparently reached a maximum when about 30 per cent. of the calculated quantity was present. From this point on, the contending decompositions proceeded in such a manner that the amount of hydroxamic acid finally obtained was rapidly diminished as the time of heating increased.

No simple method of separating the products by fractional crystallization from solvents could be found. By means of a solution of copper acetate, a precipitate was produced which consisted of cuprous oxide (due to reduction by the hydroxylamine salt) and the basic copper salt of acethydroxamic acid, $C_4H_8O_5N_2Cu_2$, described by Crismer.¹ From this mixture, pure acethydroxamic acid was prepared in the usual way by passing hydrogen sulphide through alcohol in which the copper salt was suspended.

Rough experiments have shown that hydroxylamine benzoate and hydroxylamine anisate, at temperatures slightly above their melting points, also yield the corresponding hydroxamic acids.

EXPERIMENTAL.

Hydroxylamine Formate.—Ssabanejeff² prepared this compound by the action of hydroxylamine sulphate upon barium formate. It was made more readily in a pure condition by the action of the calculated amount of anhydrous formic acid upon a weighed quantity of hydroxylamine surrounded by a freezing mixture. Considerable heat was evolved, and the product soon solidified. After an hour, the salt was drained by filtration, dried and recrystallized from alcohol. The nitrogen content was determined.

0.2595 gram gave 42.6 cc. of nitrogen at 23° and 732.4 mm.

	Calculated for CH_5O_3N .	Found.
N	17.72	17.75

Properties of Hydroxylamine Formate.—The salt crystallized in colorless needles which melted at 76°. It was soluble in water and in hot alcohol, but almost insoluble in ether or

¹ Crismer: Bull. Soc. Chim., [3] 3, 121.

² Loc. cit.

ligroin. When heated to a temperature between 78° and 80° for a short time, the fused residue gave a decided test for hydroxamic acid. If the heating was continued longer, or if the temperature rose above 80° , violent decomposition set in at once. In open vessels, the salt was observed to lose weight quite rapidly, possibly because of sublimation or dissociation, or through both causes at the same time. A sample of the salt which had stood in a desiccator over calcium chloride for several weeks was found to contain a large amount of formhydroxamic acid.

Synthesis of Formhydroxamic Acid from Carbon Monoxide and Hydroxylamine.—About 5 grams of free hydroxylamine were placed in a Liebig's absorption apparatus, and a stream of pure, dry carbon monoxide was passed through it slowly for seven hours. When acidified with dilute sulphuric acid, the reaction product gave a decided purple color with ferric chloride; but this color faded away almost instantly. It has been shown that ferric salts are easily reduced by hydroxylamine salts in acid solution. The reaction in the case of ferric chloride is expressed by the following equation:



Ferric salts of hydroxamic acids would not be exceptions to this rule. A solution of pure formhydroxamic acid was treated with an acid solution of ferric chloride; when some hydroxylamine was added, the purple color was instantly discharged.

The amount of formhydroxamic acid produced by the method described must have been very small. Experiments will be tried in which hydroxylamine will be allowed to act upon carbon monoxide under considerably increased pressures.

Hydroxylamine Acetate.—The salt employed in the following experiments was made by dropping the calculated weight of glacial acetic acid into free hydroxylamine cooled by ice. After the salt had been recrystallized from hot alcohol, it was found to be identical with the compound described by Lossen.¹

¹ Lossen: Ann. Chem. (Liebig), Supp., 6, 231.

Experiments performed in open vessels soon showed that the salt, at temperatures between 88° and 90° , sublimed so rapidly that the heat could not be applied in a satisfactory manner. To obviate this difficulty, weighed samples were placed in test tubes which, after being sealed, were heated to a temperature of 90° for different periods of time varying from one to eight hours.

When the tubes were opened, a small quantity of colorless gas escaped, and the odor of acetic acid was very noticeable. The contents of each tube were dissolved in water, and each solution was treated separately with a slight excess of a saturated solution of cupric acetate, which immediately produced a precipitate composed of cuprous oxide and the basic copper salt of acethydroxamic acid.

These precipitates were dried at a temperature of 110° , and weighed. The percentage of nitrogen in each was then determined by analysis. Upon the assumption that all of the nitrogen present in the precipitates was combined as the basic copper salt of acethydroxamic acid, $C_4H_5O_5N_2Cu_2$, the amount of acethydroxamic acid which each precipitate represented could be estimated. The results of the analyses were as follows:

Sample.	a.	b.	c.
Wt. of sample (gram)	0.5000	0.5000	0.3925
Volume of nitrogen (cc.)	24.2	36.1	28.3
Temperature ($^{\circ}$)	24.5	23.5	23.0
Pressure (mm.)	741.6	741.5	739.6
Percentage of nitrogen	5.31	7.93	7.94

	d.	e.	f.
Wt. of sample (gram)	0.3469	0.3786	0.3342
Volume of nitrogen (cc.)	30.5	33.0	29.8
Temperature ($^{\circ}$)	24.0	24.0	18.0
Pressure (mm.)	744.4	737.5	728.9
Percentage of nitrogen	9.7	9.49	9.83

The percentage yields of acethydroxamic acid calculated from these results are given in the following table:

Sample.	a.	b.	c.
Weight in grams	2	2	2
Period of heating (hours)	1	2	3
Weight of copper salts	1.59	1.07	1.10
Percentage of nitrogen	5.31	7.93	7.94
Weight of acid	0.451	0.453	0.467
Percentage yield of acid	28.0	28.1	29.0

Sample.	d.	e.	f.
Weight in grams	2	2	2
Period of heating (hours)	3.5	3.75	4.5
Weight of copper salts	0.91	0.85	0.77
Percentage of nitrogen	9.70	9.49	9.33
Weight of acid	0.493	0.428	0.401
Percentage yield of acid	30.6	26.5	24.9

These figures show that the conditions represented in column *d* were the most favorable for obtaining a large amount of acethydroxamic acid, when 2-gram samples were heated at 90°.

Several dried samples of the mixture of cuprous oxide and basic copper salt were suspended in methyl alcohol, and treated with hydrogen sulphide. When the alcoholic solution, separated from copper sulphide, was evaporated *in vacuo*, solid acethydroxamic acid remained. It was identical in properties with the compound prepared by Lossen.

THE EFFECT OF TEMPERATURE AND DILUTION ON THE CONDUCTIVITY OF ORGANIC ACIDS IN AQUEOUS SOLUTION.

BY GEORGE F. WHITE AND HARRY C. JONES.

A thoroughly systematic study of the conductivity and dissociation of organic acids, as affected by temperature as well as by dilution, has not been made since this important method of determining the strength of electrolytes has come into use. There are a few articles in the literature which deal with this subject, but a comprehensive investigation of the field is lacking, and many of the conclusions that have been reached are conflicting. In the brief review presented

here of work dealing with conductivity and dissociation at various temperatures, attention will be called mainly to matter dealing with the subject in hand, that is, the organic acids. Comparatively little reference will be made to the enormous amount of work carried out at one temperature.

It was early observed that the conductivity of electrolytes in solution changes with the temperature, and in the reverse sense to that of metals. This fact was long known without accurate or extended measurements being made to further our knowledge of the subject. Over sixty years ago Ohm¹ and Becquerel² pointed out a few facts concerning the effect of temperature on conductivity. Hankel,³ in a piece of work of wider scope than any preceding it, showed that the electrical resistance of many solutions very noticeably decreased with rising temperature, and he worked out a few general relations connecting the behavior of various substances.

E. Becker⁴ in 1850 studied the conductivity of solutions of a few of the common acids and salts between 0° and 100°, formulating some of his results in equations connecting temperature and conductivity. Later⁵ he investigated the effect of concentration. Attention may also be called to the work of Beetz,⁶ Freund,⁷ Bergren,⁸ Long⁹ and Bouty.¹⁰

The first serious and important investigation was completed in 1874 by Grottrian,¹¹ who studied the conductivity of solutions of hydrochloric acid and sulphuric acid, use being made of the alternating current method of Kohlrausch. Grottrian found that the conductivity of the hydrochloric acid solution was a linear function of the temperature between 0° and 33°, but he obtained a parabolic interpolation formula for sulphuric acid between 0° and 70°. A maximum in conductivity

¹ Pogg. Ann., **63**, 403 (1844).

² *Ibid.*, **70**, 254 (1847).

³ *Ibid.*, **69**, 255 (1846).

⁴ Ann. Chem. (Liebig), **73**, 1 (1850).

⁵ *Ibid.*, **75**, 94 (1850).

⁶ Pogg. Ann., **117**, 1 (1862).

⁷ Wied. Ann., **7**, 49 (1879).

⁸ *Ibid.*, **1**, 499 (1877).

⁹ *Ibid.*, **11**, 37 (1880).

¹⁰ Ann. Chim. Phys., [6] **3**, 498 (1884).

¹¹ Pogg. Ann., **151**, 378 (1874).

occurred at a definite dilution, which in the case of sulphuric acid became greater the higher the temperature. The solution of hydrochloric acid behaved in the opposite sense. This work was followed by that of Kohlrausch and Grotrian¹ in which were investigated many electrolytes, including nitric acid and some alkali and alkaline earth salts. They concluded that it is a practically general truth that in dilute solutions conductivity is a parabolic function of the temperature. They applied the ordinary equation of the parabola,

$$K_t = K_o(1 + \alpha t + \beta t^2),$$

in which α and β are constants depending on the nature of the electrolyte, and easily calculated, and K_t and K_o are the conductivities at t° and 0° , respectively.

In 1887 Otten² studied the influence of temperature on the conductivity of some fatty acids. He used formic, acetic, propionic and butyric acids, and showed that the resistance increases as we go up in the homologous series. In the case of all the acids, the conductivity increased with the percentage content of the solution up to a maximum and then decreased. The maximum for formic acid lay at a concentration of about 30 per cent., and for the higher members in the series it occurred at a lower concentration.

Arrhenius³ measured the conductivity of various electrolytes in dilute solutions at 18° and 52° , and by means of the formula

$$\mu_{52} = \mu_{18} (1 + \alpha_{35}^{0.34}),$$

in which μ is the molecular conductivity and α the temperature coefficient, he was able to calculate the mean temperature coefficient between these temperatures. The temperature coefficients of the more strongly dissociated electrolytes are generally smaller the greater the conductivity; hence the conductivities approach one another as the temperature rises. The change of the coefficients with the strength of the solution is not great so long as the latter remains small. Arrhenius also observed an exceedingly important fact, *viz.*, that the

¹ Pogg. Ann., **154**, 215 (1875).

² Diss., München (1887).

³ Z. physik. Chem., **4**, 96 (1889).

dissociation of phosphoric and hypophosphorous acids decreases with rise in temperature. This was a surprising discovery in the light of the old theory, which explained increase in conductivity with rise in temperature on the assumption of increase in dissociation. This question of the influence of temperature on dissociation has remained a subject of study up to the present day, and still needs a large amount of further investigation.

The work of Krannhals¹ may be mentioned here. He discovered few new relations in his study of the conductivity of some typical acids and salts, and his results generally confirmed the conclusions of Kohlrausch and Grotrian. He concluded that temperature has no effect on dissociation.

In 1895 Hans Jahn and E. Schröder² made determinations of the conductivity of aqueous solutions of formic, acetic, propionic, butyric, isobutyric and valeric acids. Each acid was investigated in solutions varying from N/2 to N/128, and at a series of temperatures ranging from 10° to 50°. They expressed their results by interpolation formulae, calculated values agreeing satisfactorily with those observed. Their method of work was not sufficiently accurate to enable them to notice a change in dissociation with temperature, and they infer therefore that it is constant. Their results, however, show a decreasing dissociation with rise in temperature in the case of valeric acid, but they assumed this to be due to the presence of impurities. Jahn therefore concluded that increase in conductivity with the temperature is a function of the decrease of ionic friction. Déguisne³ and Wood⁴ also worked in the field at this time.

In 1896 Euler⁵ studied some typical aromatic organic acids between 10° and 50° and at various dilutions. Interpolation formulae were calculated for each acid at every dilution and were found to be of the form

$$\lambda = a + bt - ct^2,$$

¹ Z. physik. Chem., **5**, 250 (1890).

² *Ibid.*, **16**, 72 (1895).

³ Diss., Strassbourg (1895).

⁴ Phil. Mag., **41**, 117 (1896).

⁵ Z. physik. Chem., **21**, 257 (1896).

where λ represents the molecular conductivity and t the temperature. The form of the equation indicates a maximum in the curve if the expression applies at higher temperatures. In every case the dissociation varied with the temperature, a maximum occurring for benzoic acid at about 25° , and for *m*-hydroxybenzoic acid at about 28° . The values for toluic acid decreased with rising temperature, but those for *m*-nitrobenzoic and salicylic acids increased. Euler offered no explanation for these inharmonious results, and further investigation seems necessary on this subject before the work can be accepted as final. There is no apparent reason why *m*-hydroxybenzoic and benzoic acid should differ so fundamentally in their behavior, and the other relations seem inconsistent.

Schaller¹ studied the conductivity of several acids, bases and salts, including a few organic acids. He made use of platinum vessels to avoid the solvent action of water on glass at the high temperatures at which he worked. The molecular conductivities were found to increase with rise in temperature, but at a diminishing rate, so that in some cases a maximum was reached, beyond which the molecular conductivity decreased. The degree of dissociation, however, in all cases decreased with rise in temperature.

In 1901 Jones and Douglas² measured the conductivity of a number of inorganic acids, bases and salts between 0° and 35° . They observed that for salts the temperature coefficients increase with rise in temperature, but noticed little change for acids and bases. Their results showed that temperature affects dissociation to no appreciable extent.

The work of Jones and West³ and of Jones and Jacobson⁴ at temperatures ranging from 0° to 35° , and of Noyes⁵ at high temperatures, has established conclusively that dissociation decreases with rise in temperature for most of the substances they investigated. Jacobson obtained this result with a few organic

¹ Z. physik. Chem., **25**, 497 (1898).

² THIS JOURNAL, **26**, 428 (1901).

³ *Ibid.*, **34**, 357 (1905).

⁴ *Ibid.*, **40**, 355 (1908).

⁵ J. Am. Chem. Soc., **26**, 134 (1904).

acids, but found an increasing dissociation with rising temperature in the case of *m*-nitrobenzoic acid and a few inorganic salts. He suggests that this was due to the influence of hydrolysis. Molecular conductivity has been shown to be in general (water being a marked exception) a parabolic function of the temperature,¹ a state of things which may be explained by the theory of hydration which Jones has put forward as a result of considerable work by himself and students. According to this theory, it would appear that all electrolytes in aqueous solution are hydrated to a certain extent, a condition which would prevent conductivity from being a linear function of the temperature, as it very probably would be if the viscosity of the medium alone were the influencing factor. He sums up the facts now known in a recent paper² to which attention is here called.

From what has been said of the work already done, it is evident that more accurate and more extended data on the conductivity of organic acids as affected by temperature, at least between 0° and 35°, should be obtained. It is intended in this preliminary paper to supply this deficiency for a number of typical acids of both the aliphatic and aromatic series, and it is hoped by further investigation to supplement these and make the work as complete as practicable. The dissociation of these acids from 0° to 35° is reserved also for a future article. To obtain the conductivity at infinite dilution necessary for this purpose, the Kohlrausch method, which involves the use of the sodium salts of these organic acids, is being employed.

EXPERIMENTAL PART.

The measurements were carried out by means of the ordinary Kohlrausch method with a Wheatstone bridge, rheostat, induction coil and telephone receiver. The bridge wire and thermometers were calibrated carefully, the latter to within 0°.01. All flasks, burettes and pipettes were calibrated for 20°. The conductivity cells were of the type used by

¹ THIS JOURNAL, 40, 402 (1908).

² *Ibid.*, 41, 19 (1909).

Jones and Bingham¹ and which have given satisfactory results in this laboratory for several years.

The measurements were made at four temperatures ranging from 0° to 35°, and at various dilutions from N/2 up to N/2048, or as near this strength as possible, this being dependent on the solubility of the acid.

The 0° bath was that made use of by Jacobson,² and fully described in his article bearing on this same subject. The cells containing the solutions which it was desired to bring to a temperature between 0° and 25° were placed in a tank through which tap water was kept flowing and stirred by its own pressure. Satisfactory results were obtained by this method, no measurements being taken until the temperature was observed to be constant within 0.°03 for at least half an hour.

The 25° and 35° baths were heated by Bunsen burners. No automatic regulator was used, the size of the flame being easily regulated by a pinchcock, so that the maximum variation in temperature was no greater than 0.°02. The baths were stirred by paddles rotated by hot-air engines.

It was necessary for the cells to remain for at least an hour in those baths kept at and below a temperature of 25°. At 35°, however, the solutions gave constant readings in the short space of half an hour. Duplicate readings were taken after an interval of five minutes to insure constant temperature. The final results also were the average of three measurements, taken with the minimum as near the center of the bridge as convenient. As few plugs as possible were removed from the resistance box.

Organic Acids.—The organic acids in most instances were obtained from Kahlbaum. They were purified by crystallization or distillation, as was most suitable, and tested as to their purity by their melting points or boiling points. The liquids were made up into solutions which were standardized by potassium hydroxide dissolved in absolute alcohol, phenolphthalein being employed as the indicator. As the acid was

¹ THIS JOURNAL, 34, 481 (1905).

² *Ibid.*, 40, 355 (1908).

dissolved in conductivity water, the absence of carbonic acid was thus assured, and the titration made reliable. The most concentrated solution being brought to the desired normality, the more dilute solutions were made up from this. The solutions of the solid acids were obtained in the same manner, the mother solution being made up by weight and standardized by titration.

Cell Constants.—The cell constants were obtained in the usual manner by the aid of a N/50 solution of pure potassium chloride. Kohlrausch's value for the molecular conductivity of this solution is 129.7 (Siemen's units); adding to this the amount due to the conductivity of the water, the constants can easily be calculated. For those cells in which the platinum plates were close together a N/500 solution of potassium chloride was used, the conductivity of which was measured in the cells standardized with the N/50 solution. The constants were redetermined frequently although absolutely no change, within the limits of experimental error, was found in many for several months. With due caution as to removing the electrodes from the cell cups this result is assured, and more reliance can be placed on the measurements. At the temperatures at which we worked there was no noticeable effect due to the solubility of the glass.

Water.—The conductivity water employed in making up the solutions was distilled according to the method previously used in this laboratory and frequently described. The process consists simply in the distillation of ordinary distilled water from a potassium bichromate solution acidified with sulphuric acid, to destroy organic matter and retain ammonia. The distillate is then distilled from a flask containing barium hydroxide, and finally redistilled through a block tin condenser, the last two operations being carried out in one piece of apparatus. The water thus obtained had a conductivity at 25° varying from 1.2×10^{-6} to 1.7×10^{-6} . It was kept in glass bottles long used for the purpose, and withdrawn by a siphon and protected from carbon dioxide in the air by soda-lime.

Results.—The results are tabulated in the following pages,

molecular conductivities (μ_v) being expressed in Siemen's units. The dissociation (α) at 25° was calculated by the aid of Ostwald's values for the conductivity at infinite dilution. The temperature coefficients expressed in conductivity units and in percentages need no explanation.

Table I.—Acetic Acid. Molecular Conductivity and Dissociation.

V.	0°.	9.°2.	25°.		35°.
	μ_v .	μ_v .	μ_v .	α .	μ_v .
2	1.270	1.560	2.089	0.57	2.359
8	2.656	3.292	4.342	1.19	4.948
32	5.328	6.612	8.699	2.39	9.912
128	10.48	13.04	17.11	4.69	19.46
512	20.45	25.40	33.24	9.11	37.75
1024	28.03	34.95	45.87	12.57	52.09
2048	39.05	48.65	63.00	17.26	70.89

Temperature Coefficients.

V.	0°—9.°2.		9.°2—25°.		25°—35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
2	0.03	2.49	0.03	2.15	0.03	1.30
8	0.07	2.61	0.07	2.02	0.06	1.40
32	0.14	2.62	0.13	2.00	0.12	1.39
128	0.28	2.66	0.26	1.98	0.24	1.37
512	0.54	2.63	0.50	1.96	0.45	1.36
1024	0.72	2.57	0.69	1.95	0.62	1.32
2048	1.04	2.67	0.91	1.87	0.79	1.25

Table II.—Propionic Acid. Molecular Conductivity and Dissociation.

V.	0°.	6.°9.	25°.		35°.
	μ_v .	μ_v .	μ_v .	α .	μ_v .
2	1.030	1.217	1.700	0.47	1.913
8	2.291	2.700	3.704	1.03	4.207
32	4.631	5.450	7.436	2.07	8.422
128	9.004	10.60	14.57	4.06	16.50
512	17.47	20.59	28.40	7.91	32.14
1024	23.82	28.03	38.94	10.85	44.06
2048	33.43	39.24	53.47	14.89	60.28

Temperature Coefficients.

V.	0°-6.°9.		6.°9-25°.		25°-35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
2	0.03	2.63	0.03	2.19	0.02	1.25
8	0.06	2.59	0.06	2.05	0.05	1.36
32	0.12	2.56	0.11	2.01	0.10	1.33
128	0.23	2.58	0.22	2.07	0.19	1.32
512	0.45	2.59	0.43	2.10	0.37	1.32
1024	0.61	2.56	0.59	2.11	0.51	1.31
2048	0.84	2.52	0.79	2.01	0.68	1.27

Table III.—*n*-Butyric Acid. Molecular Conductivity and Dissociation.

V.	0°.	9.°4.	25°.		35°.
	μ	μ_v	μ_v	α	μ_v
2	1.090	1.341	1.730	0.49	1.930
8	2.501	3.062	3.891	1.09	4.351
32	5.072	6.230	7.902	2.22	8.801
128	10.00	12.23	15.45	4.34	17.14
512	19.44	23.79	29.86	8.39	33.00
1024	26.82	32.83	41.22	11.60	45.26
2048	37.37	45.63	57.20	15.96	62.71

Temperature Coefficients.

V.	0°-9.°4.		9.°4-25°.		25°-35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
2	0.03	2.44	0.03	1.87	0.02	1.16
8	0.06	2.38	0.05	1.74	0.05	1.19
32	0.12	2.43	0.11	1.72	0.09	1.14
128	0.24	2.44	0.21	1.69	0.17	1.09
512	0.46	2.38	0.39	1.64	0.31	1.05
1024	0.64	2.38	0.54	1.64	0.40	0.98
2048	0.88	2.35	0.74	1.61	0.55	0.96

Table IV.—Phenylacetic Acid. Molecular Conductivity and Dissociation.

V.	0°.	13.°25.	25°.		35°.
	μ_v	μ_v	μ_v	α	μ_v
32	9.001	11.762	14.151	4.00	15.90
128	17.82	23.39	27.96	7.88	31.26
512	33.35	43.51	52.39	14.76	58.55
1024	45.68	59.59	71.63	20.18	79.84
2048	61.00	79.49	95.50	26.87	106.3

Temperature Coefficients.

V.	0°—13.°25.		13.°25—25°.		25°—35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
32	0.21	2.32	0.20	1.73	0.18	1.23
128	0.41	2.32	0.40	1.70	0.33	1.18
512	0.77	2.30	0.76	1.72	0.62	1.18
1024	1.05	2.30	1.03	1.72	0.82	1.15
2048	1.40	2.29	1.36	1.71	1.08	1.13

Table V.—Malonic Acid. Molecular Conductivity and Dissociation.

V.	0°.	4.°9.	25°.		35°.
	μ_v .	μ_v .	μ_v .	α .	μ_v .
2	11.81	13.34	19.61	5.48	22.51
8	23.19	26.20	38.40	10.67	44.03
32	43.51	49.25	72.23	20.18	82.55
128	78.30	88.83	129.8	36.26	148.2
512	127.1	143.4	208.7	58.30	237.4
1024	153.3	173.2	251.2	70.17	284.8
2048	176.9	199.1	289.1	80.76	326.6

Temperature Coefficients.

V.	0°—4.°9.		4.°9—25°.		25°—35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
2	0.31	2.64	0.31	2.34	0.29	1.48
8	0.61	2.66	0.61	2.32	0.58	1.47
32	1.17	2.69	1.14	2.32	1.03	1.43
128	2.09	2.67	2.04	2.30	1.84	1.42
512	3.33	2.62	3.25	2.27	2.87	1.38
1024	4.06	2.65	3.88	2.24	3.36	1.34
2048	4.53	2.56	4.48	2.25	3.75	1.30

Table VI.—Succinic Acid. Molecular Conductivity and Dissociation.

V.	0°.	5.°7.	25°.		35°.
	μ_v .	μ_v .	μ_v .	α .	μ_v .
8	4.570	5.371	8.032	2.25	9.251
32	9.211	10.72	16.01	4.50	18.36
128	18.24	21.35	31.24	8.78	35.80
512	34.75	40.59	59.34	16.62	67.87
1024	47.89	55.91	81.31	22.84	92.89
2048	64.61	75.29	109.6	30.80	124.8

Temperature Coefficients.

V.	0°—5.°7.		5.°7—25°.		25°—35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
8	0.14	3.07	0.14	2.57	0.12	1.52
32	0.28	3.03	0.27	2.56	0.24	1.47
128	0.55	2.99	0.51	2.40	0.46	1.46
512	1.02	2.95	0.97	2.39	0.85	1.44
1024	1.41	2.94	1.32	2.36	1.16	1.42
2048	1.87	2.90	1.78	2.36	1.52	1.39

Table VII.—o-Phthalic Acid. Molecular Conductivity and Dissociation.

V.	0°.	8.°23.	25°.		35°.
	$\mu v.$	$\mu v.$	$\mu v.$	$\alpha.$	$\mu v.$
64	55.98	66.45	85.92	24.28	96.48
128	74.56	88.32	114.8	32.43	128.9
512	122.3	145.7	189.2	53.46	212.5
1024	148.2	177.1	231.9	65.48	259.7
2048	174.2	208.4	272.7	77.03	306.0

Temperature Coefficients.

V.	0°—8.°23.		8.°23—25°.		25°—35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
64	1.27	2.27	1.16	1.75	1.06	1.23
128	1.67	2.24	1.58	1.79	1.41	1.23
512	2.84	2.33	2.59	1.78	2.33	1.23
1024	3.51	2.37	3.27	1.85	2.78	1.20
2048	4.16	2.39	3.83	1.84	3.33	1.22

Table VIII.—Benzoic Acid. Molecular Conductivity and Dissociation.

V.	0°.	15.°8.	35°		35°.
	$\mu v.$	$\mu v.$	$\mu v.$	$\alpha.$	$\mu v.$
64	13.42	19.08	22.29	6.26	25.40
128	18.79	26.93	31.39	8.82	35.71
512	36.00	51.30	59.79	16.79	67.81
1024	47.63	68.33	79.56	22.36	90.11
2048	64.95	91.30	106.0	29.78	119.7

25°? see 43, 183

Temperature Coefficients.

V.	0°—15.08.		15.08—25°.		25°—35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
64	0.36	2.67	0.35	1.83	0.31	1.40
128	0.50	2.66	0.49	1.81	0.43	1.38
512	0.97	2.69	0.92	1.81	0.80	1.35
1024	1.26	2.64	1.22	1.79	1.06	1.33
2048	1.67	2.57	1.60	1.75	1.37	1.30

Table IX.—Salicylic Acid. Molecular Conductivity and Dissociation.

V.	0°.	6.9°.	25°.		35°.
	$\mu v.$	$\mu v.$	$\mu v.$	$\alpha.$	$\mu v.$
64	....	..	80.50	22.55	92.80
128	62.65	75.59	108.3	30.33	125.1
512	105.4	126.4	181.2	50.76	207.0
1024	130.7	156.9	223.2	62.52	255.4
2048	153.8	183.9	259.9	72.80	295.7

Temperature Coefficients.

V.	0°—6.9°.		6.9°—25°.		25°—35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
64	..	..	..	..	1.23	1.53
128	1.88	2.99	1.83	2.42	1.68	1.55
512	3.12	2.96	3.00	2.37	2.58	1.42
1024	3.80	2.91	3.63	2.31	3.22	1.41
2048	4.36	2.84	4.16	2.26	3.58	1.38

Table X.—Gallic Acid. Molecular Conductivity and Dissociation.

V.	0°.	6.5°.	25°.		35°.
	$\mu v.$	$\mu v.$	$\mu v.$	$\alpha.$	$\mu v.$
64	9.790	11.66	16.90	4.75	19.36
128	14.01	16.55	23.60	6.63	27.10
512	28.89	34.08	48.33	13.58	55.12
1024	37.84	44.63	62.50	17.56	71.18
2048	51.50	60.72	85.02	23.89	96.7

Temperature Coefficients.

V.	0°—6.°5.		6.°5—25°.		25°—35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
64	0.29	2.94	0.28	2.43	0.25	1.46
128	0.39	2.79	0.38	2.30	0.35	1.48
512	0.80	2.77	0.77	2.26	0.68	1.41
1024	1.05	2.76	0.97	2.17	0.87	1.39
2048	1.42	2.75	1.31	2.16	1.17	1.38

Table XI.—Cinnamic Acid. Molecular Conductivity and Dissociation.

V.	0°.	5.°3.	25°.		35°.
	μ_v .	μ_v .	μ_v .	α .	μ_v .
512	26.50	30.67	44.60	12.70	50.70
1024	36.40	42.11	61.22	17.40	69.63
2048	49.69	57.40	83.45	23.71	94.81

Temperature Coefficients.

V.	0°—5.°3.		5.°3—25°.		25°—35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
512	0.79	2.97	0.71	2.31	0.61	1.37
1024	1.08	2.96	0.97	2.30	0.84	1.37
2048	1.46	2.93	1.32	2.30	1.14	1.36

Table XII.—o-Aminobenzoic Acid. Molecular Conductivity and Dissociation.

V.	0°.	7.5°.	25°.		35°.
	μ_v .	μ_v .	μ_v .	α .	μ_v .
64	3.071	4.172	7.150	2.01	9.001
128	4.692	6.283	10.71	3.02	13.39
512	10.901	14.31	23.26	6.55	28.96
1024	16.03	20.48	33.53	9.45	41.57
2048	21.93	28.30	45.26	12.75	55.78

Temperature Coefficients.

V.	0°—7.°5.		7.°5—25°.		25°—35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
64	0.15	4.78	0.17	4.08	0.19	2.59
128	0.21	4.52	0.25	3.98	0.27	2.57
512	0.45	4.17	0.51	3.58	0.57	2.45
1024	0.65	4.03	0.72	3.46	0.81	2.40
2048	0.85	3.87	0.97	3.43	1.05	2.33

Table XIII.—*p*-Aminobenzoic Acid. Molecular Conductivity and Dissociation.

V.	0°.	10.°19.	25°.		35°.
	$\mu v.$	$\mu v.$	$\mu v.$	$\alpha.$	$\mu v.$
64	3.711	5.136	7.370	2.08	8.919
128	5.346	7.527	10.84	3.05	12.97
512	12.57	17.39	24.54	6.91	29.06
1024	18.87	25.71	35.07	9.88	41.31
2048	28.32	37.21	50.13	14.12	58.56

Temperature Coefficients.

V.	0°—10.°19.		10.°19—25°.		25°—35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
64	0.14	3.78	0.15	2.92	0.16	2.10
128	0.21	4.00	0.22	2.97	0.21	1.96
512	0.47	3.76	0.48	2.78	0.45	1.84
1024	0.67	3.57	0.63	2.46	0.62	1.79
2048	0.87	3.08	0.87	2.35	0.84	1.68

Table XIV.—Sulphanilic Acid. Molecular Conductivity and Dissociation.

V.	0°.	6.°3.	25°		35°.
	$\mu v.$	$\mu v.$	$\mu v.$	$\alpha.$	$\mu v.$
32	21.80	27.25	47.20	13.26	60.0
128	40.66	50.89	87.51	24.58	110.2
512	74.25	91.33	152.8	42.82	188.3
1024	96.40	118.1	193.0	54.23	237.0
2048	121.5	148.4	235.2	66.36	281.5

Temperature Coefficients.

V.	0°—6.°3.		6.°3—25°.		25°—35°.	
	Cond. units.	Per cent.	Cond. units.	Per cent.	Cond. units.	Per cent.
32	0.88	4.03	1.07	3.91	1.28	2.71
128	1.62	3.99	1.96	3.85	2.27	2.59
512	2.71	3.65	3.29	3.60	3.55	2.33
1024	3.45	3.57	4.01	3.39	4.40	2.28
2048	4.27	3.52	4.53	3.06	4.63	1.97

Formic and oxalic acids are omitted from the list of acids investigated as it was found that they decompose in solution in the presence of the platinized electrodes. This decomposition proceeds so rapidly at high temperatures and dilutions

that there is no means of ascertaining when the solutions have come to constant conductivity. With formic acid it was noticed that constant readings could not be obtained within the short space of a few seconds, the conductivity falling off so rapidly. Conversion of the platinum black of the electrodes into platinum white, by heating in the flame of the blast lamp, lessened but did not entirely eliminate the trouble, so it was deemed best to leave the series of acids incomplete, rather than to give results which could not be absolutely relied upon. The same decomposition took place with gallic acid, but so slowly that good measurements were possible. The solution darkened when in contact with the electrodes, presumably owing to the formation of a small amount of pyrogallic acid, but the conductivity increased very gradually.

The dissociation constants at 25°, calculated according to Ostwald's dilution formula,

$$K = \frac{\alpha^2}{v(1 - \alpha)},$$

are given in Table XV. No extended discussion on them seems necessary, as they are of the same order of magnitude as those obtained by Ostwald¹ in his comprehensive study of the affinity constants of organic acids at 25°. It is interesting to note the dilution at which the second hydrogen of the dibasic acids begins to dissociate. The dissociation constants of malonic, succinic and *o*-phthalic acids increase markedly from the dilution $V = 1024$ to that of $V = 2048$. It is therefore between these dilutions that the acidity of the acid increases. The results with these three acids compare very favorably with Ostwald's figures, and the constants for malonic and succinic acids agree satisfactorily with those of Walden.²

The increase with dilution in the values of the constants of *o*- and *p*-aminobenzoic acids should be noticed, and, as Ostwald³ concluded, is probably caused by the breaking down of the inner salts on dilution. Further mention will be made of this fact.

¹ *Z. physik. Chem.*, **3**, 170 (1889).

² *Ibid.*, **7**, 433 (1891).

³ *Ibid.*, **3**, 261 (1889).

Table XV.—Dissociation Constants $\times 10^4$ at 25°.

V.	Acetic acid.	Propionic acid.	Butyric acid.	Phenyl-acetic acid.	Malonic acid.	Succinic acid.	o-Phthalic acid.
2	0.167	0.113	0.119	...	15.9	...	..
8	0.180	0.135	0.151	...	16.1	0.651	..
32	0.181	0.137	0.157	0.517	15.9	0.662	..
128	0.180	0.134	0.154	0.525	16.1	0.655	12.1
512	0.178	0.133	0.150	0.500	15.9	0.660	12.0
1024	0.177	0.129	0.149	0.498	16.1	0.661	12.1
2048	0.176	0.128	0.148	0.482	16.6	0.669	12.6

V.	Benzoic acid.	Salicylic acid.	Gallic acid.	Cinnamic acid.	o-Amino-benzoic acid.	p-Amino-benzoic acid.	Sulphanilic acid.
64	0.654	10.3	0.370	...	0.647	0.688	..
128	0.666	10.3	0.368	...	0.740	0.752	6.26
512	0.662	10.2	0.416	0.359	0.897	0.100	6.26
1024	0.628	10.2	0.365	0.358	0.962	0.106	6.27
2048	0.617	9.5	0.366	0.360	0.910	0.113	6.29

Nearly all the acids investigated have temperature coefficients, expressed either in conductivity units or in percentages, which decrease with rise in temperature and with increase in dilution. This fact coincides with the theory of hydration of Jones referred to above. From the fact that in solutions containing metallic cations large temperature coefficients of conductivity are obtained, these coefficients being greatest in the most dilute solutions, it is clear that it is such ions which are largely hydrated in solutions. We should expect these large temperature coefficients if the ions are hydrated, since with rise in temperature the hydration would be greatly diminished and the velocity of the ions correspondingly increased; further, that the hydration would be greatest in dilute solutions where the mass action of the water comes most strongly into play, and thus rise in temperature produces a greater effect. With acids, however, there is probably not such enormous hydration. The temperature coefficients decrease regularly with dilution and rise in temperature and are generally small and of the same order of magnitude. The viscosity of the medium is the prime factor which influences increase in conductivity of acids with rise in temperature.

We turn to a fundamental part of the problem when we ask—

what function of the temperature is the conductivity of these acids? The results for each acid are shown graphically in Figures 1-4, in which conductivities are plotted as ordinates against temperatures as abscissae. It seems to be true generally that the conductivity of these organic acids is a *para-*

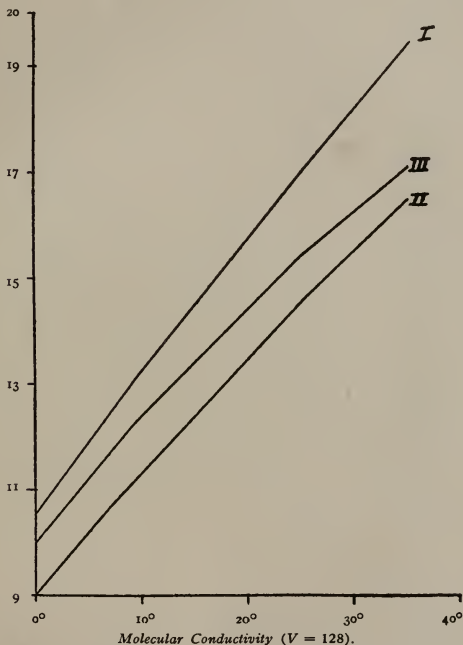


Fig. I.—I, Acetic acid; II, Propionic acid; III, Butyric acid.

bolic function of the temperature. The following table (XVI) gives values for μ_0 and the constants a and b in the equation

$$\mu = \mu_0 + at + bt^2,$$

where μ is the conductivity at any temperature t , μ_0 the conductivity at 0°, a and b are constants dependent on the nature

of the acid. The dilution selected was $N/128$, and conductivities at 0° , 25° and 35° were used in obtaining the constants.

The last two columns of the table give values for the conductivities observed at the temperature t , and those calculated

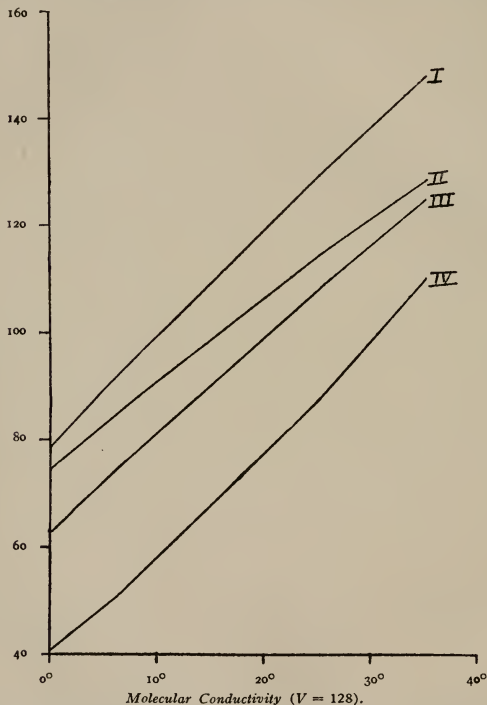


Fig. II.—I, Malonic acid; II, *o*-Phthalic acid; III, Salicylic acid; IV, Sulphanilic acid.

by the aid of the interpolation formulae. The agreement is seen to be satisfactory.

As exceptions to the statement made previously that acids have small temperature coefficients of conductivity, it is

noticed that sulphanilic acid, and *o*- and *p*-aminobenzoic acids have very large percentage temperature coefficients. This result is not due to hydrolysis, as the greatest effect would be evidenced in the most dilute solutions, whereas the

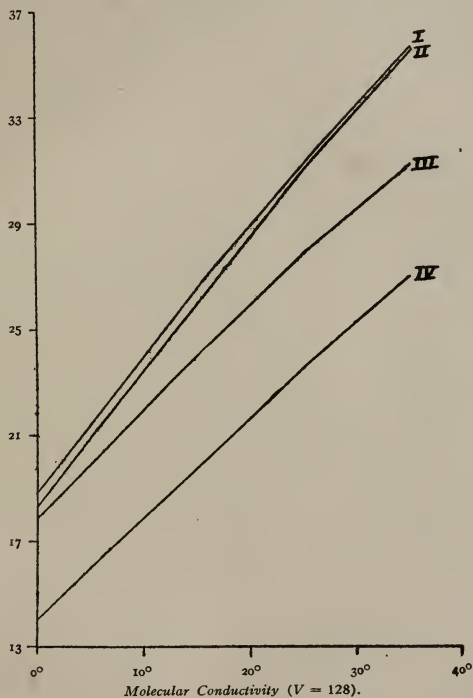


Fig. III.—I, Benzoic acid; II, Succinic acid; III, Phenylacetic acid; IV, Gallic acid.

temperature coefficients *decrease* with dilution. Also the conductivities of sulphanilic acid and *o*-aminobenzoic acid are not parabolic functions of the temperature. Here the temperature coefficients expressed in conductivity units increase

with rise in temperature, this increase being so great as to preclude conformity of behavior with the other acids. The probable cause of these discrepancies is to be found in the fact that these three acids form internal salts, having both basic and acidic groups. These internal salts would be broken down by rise in temperature, and the free acid would necessarily

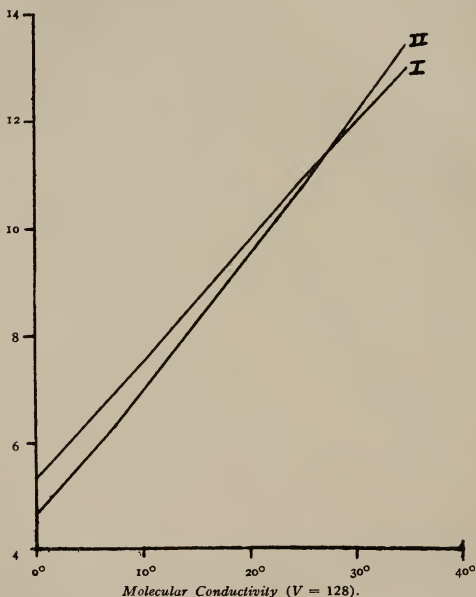


Fig. IV.—I, *p*-Aminobenzoic acid; II, *o*-Aminobenzoic acid.

conduct more than the salt itself. This theory is supported by the fact that *o*-aminobenzoic acid has much larger percentage temperature coefficients than the para acid, and also that the coefficients in conductivity units increase largely with the temperature, in consequence of the greater tendency of the ortho acid (whose salt-forming groups are nearer to-

gether in space) to form an internal salt. This point will be further tested by a study of other amino acids. This work is being continued in this laboratory.

Table XVI.

Acid.	μ_o .	a .	b .	t .	μ_t obs.	μ_t calc.
Acetic	10.48	0.287	—0.000856	9.°2	13.04	13.05
Propionic	9.00	0.244	—0.000856	6.°9	10.60	10.64
Butyric	10.00	0.253	—0.00140	9.°4	12.23	12.26
Phenylacetic	17.82	0.460	—0.00217	13.°25	23.39	23.44
Malonic	78.30	2.217	—0.00628	4.°9	88.83	89.00
Succinic	18.24	0.567	—0.00184	5.°7	21.35	21.40
<i>o</i> -Phthalic	74.56	1.752	—0.00571	8.°23	88.32	88.58
Benzoic	18.79	0.556	—0.00207	15.°8	26.93	27.04
Salicylic	62.65	1.919	—0.00411	6.°9	75.59	75.68
Gallic	14.01	0.408	—0.000982	6.°5	16.55	16.62
<i>p</i> -Aminobenzoic	5.35	0.215	—0.000189	10.°19	7.53	7.52

PHYSICAL CHEMICAL LABORATORY,
JOHNS HOPKINS UNIV., October, 1909.

REPORT.

RECENT PROGRESS IN OUR KNOWLEDGE OF THE RADIOACTIVE ELEMENTS.

I. Radioactive Radiations.

Radioactive substances are detected by means of the radiations which they emit. This property of emitting radiations is a very important one and through it our knowledge of the internal structure of the atom has been greatly increased. The various radiations are of four kinds, the α -, β -, and δ -particles, and the γ -rays.

The α -particles consist of positively charged bodies of atomic size moving with a velocity almost as great as that of light, 300,000 kilometers per second. They are very similar to the positive carriers found in anode and canal rays. The β -particles are very swiftly moving negative electrons. The α - and β -particles possess such a great velocity that they produce intense ionization when passing through a gas. On the other hand, the δ -particles move at the rate of only about $3.3 (10)^{-8}$ cm. per second and do not ionize the gas through which they pass. The γ -rays are very similar to X-rays and cannot be deflected by electric or magnetic fields. This shows

that the γ -rays consist, not of charged particles, but either of uncharged particles or of electromagnetic pulses.

II. The α -Particles.

The absorption of the various radiations appears to be due mainly to two causes: loss of energy, which produces a gradual loss of speed, and scattering, which brings about a diminution in the number of particles in the primary beam. The β -particles, being very small, are believed to penetrate atoms lying in their path. As they are easily deflected by electric and magnetic fields, the intense fields within the atoms make their path very irregular. For this reason the problem of tracing the history of a β -particle is very complex and beset with many difficulties, owing largely to our ignorance of the structure of an atom. The α -particle, however, is of atomic size so that while its velocity is very great, it pursues practically a rectilinear course. This makes the study of the motion of an individual α -particle comparatively simple.

Rutherford and others have found that all α -particles are emitted by any radioactive product at the same velocity and that the α -particles from various radioactive products differ only in their velocity of ejection. In passing through matter their velocity decreases and when it falls below a certain critical value, $0.82 (10)^9$ cm. per second,¹ the particles cease to ionize the air, to affect the photographic plate, or to produce phosphorescence. The distance which the α -particle will traverse in air under standard conditions of pressure and temperature is known as its range. The range of the α -particle is an important constant for any radioactive product. It differs for α -particles coming from different radioactive products. Rutherford gives an empirical formula,

$$V = 0.348 V_0 \sqrt{r + 1.35},$$

by means of which we can calculate the velocity V of an α -particle for any point in its path if we know the range. V_0 is the initial velocity of the α -particle emitted by radium C and is equal to $2.06 (10)^9$ cm. per second, and r is the remaining part of the range which the α -particle has yet to traverse from the point in its path which is being considered.

Recently Duane² has attacked the problem as to whether an α -particle loses its charge at the same time that it ceases to ionize the surrounding gas. His conclusion is that it does. The α -particles, when they impinge upon a solid body, pro-

¹ Rutherford: *Phil. Mag.*, **12**, 140 (1906). Lerch: *Z. Elek. Chem.*, **13**, 381 (1907).

² *Am. J. Sci.*, **26**, Nov. (1908).

duce δ -particles at its surface. Duane finds that beyond their range the α -particles cease to produce these secondary δ -particles. At present, therefore, we have no means of detecting the α -particle when its velocity is less than $1.8(10)^9$ cm. per second, so that if any element emits α -particles with a velocity less than this, there is no direct method of discovering it.

It has been known for some time that helium accumulates in radium, actinium, and thorium compounds and it has often been suggested that this helium consists of the α -particles after they have lost their charge. But this is difficult to prove. The value of e/m (e being the charge and m the mass) is known for the α -particle. If e could be measured, m could be determined and if its value should come out about the same as that for the helium atom, the evidence that the α -particle is simply a charged helium atom moving with a very great velocity would be very strong. Now it is possible to find the charge which a beam of α -particles will carry to a plate. If the number of carriers could be counted, then e could be calculated and m determined from the known ratio e/m . α -Particles striking upon a zinc sulphide screen produce scintillations which can easily be seen and Regener¹ has used this method for counting the α -particles, each α -particle being supposed to strike the zinc sulphide and to produce a scintillation. Rutheford and Geiger² have recently attained the same object in a very ingenious manner by magnifying the ionizing power of the α -particles. Notwithstanding its enormous power to ionize gases, an α -particle entering an ionization chamber would not produce enough ions in the gas to give rise to a current that could be easily detected. Townsend³ has worked out the conditions under which ions can be formed by collision between neutral gas molecules and ions moving in a strong electric field. Suppose that the current between parallel plates immersed in a gas at low pressures is observed when the air is ionized by X-rays. In a weak field the current increases with the voltage and soon reaches a constant value, the saturation current. If the field is increased beyond a certain point, however, the current rises rapidly and Townsend showed that this was due to the production of fresh ions in the gas by the collision of negative ions with the gas molecules. Under such conditions the small current through the gas due to an external ionizing agency may be increased hundreds or even thousands of

¹ Ber. d. physik. Ges., **10**, 78 (1908).

² P. Roy. Soc., A, **81**, 141.

³ Phil. Mag., Feb., 1901; Jan., 1902; Apr., Sept. and Nov., 1903.

times. Rutherford and Geiger place their charged plates near a small opening from which α -particles are emerging. As an α -particle enters the electric field between the plates it produces ions by collision, and these ions are given sufficient velocity by the electric field to produce other ions by collision with the neutral gas molecules. The result is that sufficient current is produced between the plates to cause a kick in the electrometer needle. In this way the α -particles can easily be counted.

Rutherford and Geiger found that the number of α -particles entering the opening, and also the interval between successive throws of the electrometer, varied within quite wide limits. This is to be expected from the theory of probability, upon which the present kinetic theory of gases is based. The α -particles from uranium, thorium, radium and actinium compounds have been counted by Rutherford and Geiger, who believe that this method of automatic increase of ionization by collision can be used to extend very considerably the range of measurement of minute quantities of radioactive matter and that under good conditions the β -particles can be counted in the same way. They found for a given intensity of radiation that the number of α -particles entering the detecting vessel varied as the area of the aperture and that for radium C the α -particles are projected equally in all directions. As an example of their results the following table is given. Q_0 is the number of α -particles expelled per second per gram of radium. After making a correction, the value $3.4 (10)^{10}$ is taken for Q_0 :

Table I.

Gas.	Pressure in detecting vessel.	Voltage.	Diameter of aperture.	Number of throws of electrometer.	Q_0 .
Air	3.75	1200	1.23	161	$3.20 (10)^{10}$
CO ₂	4.8	1360	1.23	59	$3.10 (10)^{10}$
CO ₂	4.8	1360	1.23	118	$3.30 (10)^{10}$
CO ₂	4.2	1320	1.92	194	$3.43 (10)^{10}$

From experiments of Bragg and Boltwood it appears very probable that the same number of α -particles is expelled per second from radium and each of the α -ray products in equilibrium with it. This is also supported by the fact that radium, the radium emanation, radium A, and radium C each produce about the same amount of ionization when the four products are in equilibrium. This is not true of all the radioactive elements, however. Bronson¹ finds evidence that an

¹ Phil. Mag., Aug., 1908.

atom of thorium C, in breaking up, gives off the same number of α -particles as an atom of thorium B and that an atom of the thorium emanation gives off four times this number; also that an atom of actinium emanation, in breaking up, gives off twice as many α -particles as an atom of its active deposit. Rutherford and Geiger¹ assume that each atom of the α -ray products of radium ejects one α -particle when it breaks down. As there are four radium products which emit α -particles, it would follow that the number of α -particles emitted per second per gram of radium in equilibrium is $4 \times 3.4 (10)^{10}$ and that in one gram of radium, $3.4 (10)^{10}$ radium atoms break up per second.

Knowing the number of α -particles produced per second by radium and measuring the total charge which they carry, we get the charge on each particle. Rutherford and Geiger¹ allow the charge to accumulate on an insulated plate exposed to one of the active products. The whole is placed in a very good vacuum to prevent any loss of charge by a current through ionized gas. It is also necessary to use a strong magnetic field, for the α -particles, in passing through matter, liberate a large number of δ -particles. In a moderately strong field the δ -particles describe very small orbits and return to the surface from which they were emitted. The field also deflects any β -particles that might otherwise charge the insulated plate. The result of Rutherford and Geiger's work is to show that E , the charge on the α -particle, is $9.3 (10)^{-10}$ electrostatic units. From calculations based upon the heating effect of radium and where it is assumed that this is due to the kinetic energy of the α -particles, the value $9.1 (10)^{-10}$ electrostatic units for E is obtained.

Using the results of their experiments, Rutherford and Geiger calculate the value of the following quantities:

Table II.

E (charge on an α -particle) = $9.3 (10)^{-10}$ electrostatic units.

e (charge on a negative corpuscle) = $4.65 (10)^{-10}$ electrostatic units.

Atoms in one gram hydrogen = $6.2 (10)^{23}$.

Mass of hydrogen atom = $1.6 (10)^{-24}$ gram.

Avogadro's constant = $2.72 (10)^{19}$.

E/M (M is mass of α -particle) = $5.07 (10)^3$ electromagnetic units.

$M = 3.84$.

Mass of helium atom = 3.96 .

¹ P. Roy. Soc., A, **81**, 141, etc.

Number of atoms of radium breaking up per gram per second = $3.4 (10)^{10}$.

Volume of radium emanation produced per second per gram radium = $1.25 (10)^{-9}$ cc.

Volume of radium emanation in equilibrium with one gram radium = 0.585 cubic mm.

Amount of helium produced per gram radium per day = 0.43 cubic mm.

Calculated heating effect of one gram radium = 113 gram cal. per hour.

Calculated half-period of radium = 1750 years.

Some of these values have recently been verified by other experimenters. In the electrolysis of a monovalent salt, 96550 coulombs are carried by N atoms, so that

$$Ne = 3 (10)^9 \times 96550 \text{ electrostatic units.}$$

Applying the gas laws to emulsions, Perrin¹ finds $N = 71 (10)^{22}$ and $e = 4.1 (10)^{-10}$. Quite recently Millikan² has repeated the Thomson-Wilson determination of e and obtains a mean value of $4.65 (10)^{-10}$ electrostatic units. He caused expansion clouds to be formed in alcohol as well as in water. He finds that many of the droplets have several—some as high as six—charges on them. Boltwood³ finds the half-period value of radium to be about 2000 years, the experimental error being such as to make his results too large. In any series of successive disintegrating radio products, A, B, C, etc., in equilibrium, the number of atoms of the parent substance disintegrating per second is equal to the number of atoms of each successive product disintegrating per second. Let $\lambda_1, \lambda_2, \lambda_3$, etc., be the respective fractions of the total amounts of each product which undergo change each second. Then $\lambda_1 A_1 = \lambda_2 B_2 = \lambda_3 C_3$, etc., where A_1, B_2 , etc., are the number of atoms of A, B, etc., present. Since radium decays so slowly it is difficult to find its rate of disintegration. If, however, the parent substance (A) from which radium is formed can be separated from a primary uranium mineral (where the age is certainly sufficient for radioactive equilibrium to have been reached), and the amount (λ_1) of radium produced by this parent can be determined and compared directly with the amount (B_2) of radium with which it was associated in the mineral, it is possible to get quite an accurate value for the constant (λ_2) of change of radium. Boltwood

¹ Compt. Rend., 147, 594 (1908).

² Report before Am. Phys. Soc., Oct. 23, 1909.

³ Am. J. Sci., June, 1908.

separated out ionium (A_1) from uranium minerals. He found the amount of radium in equilibrium with this ionium and also the rate (λ_1) of production of radium from ionium. Five solutions of ionium were used. As a result he found

$$\lambda_2 = \frac{\lambda_1 A_1}{B_2} = 2000 \text{ years for the half-period value.}$$

Dewar¹ has made a series of measurements of the rate of production of helium from radium which agrees very well with the above value, calculated upon the assumption that the α -particles are charged helium atoms. He used the 70 mg. of very pure radium chloride with which Thorpe² had determined the atomic weight of radium. By using a radiometer he was able to detect increases of helium in quantities as small as that produced from 10 mg. of radium bromide in a few hours. He finds that 0.37 cubic mm. of helium accumulates in 1 gram of radium per day. This agrees very well with the calculated value.

The above evidence then is very strong that the α -particle is a charged helium atom. In addition Rutherford and Roysds³ have shown that helium can be obtained from accumulated α -particles, quite independently of the active matter from which they are expelled.

From these discoveries concerning the nature of the α -particle it must be concluded that the atoms of known radioactive elements are in part made up of helium atoms, which are liberated at definite stages during the disintegration. We also know that these radioactive elements contain several β -particles. J. J. Thomson,⁴ in a very important paper, shows by three entirely independent methods that the number of β -particles in the atom of any element is about the same as the number representing its atomic weight. The helium atom would then contain at least four corpuscles.

The above results⁵ can be used to calculate the atomic weights of various radioactive products. In the uranium-radium series are several β -ray and rayless products. Assuming that no mass comparable in size to the hydrogen atom is expelled under these conditions and taking the atomic weight of helium as 4, we have: Uranium, 238.5; uranium X, 234.5; ionium, 230.5; radium, 226.5; emanation, 222.5; radium A, 218.5; radium B, 218.5; radium C, 214.5; radium D, E, and F (radio-lead), 210.5; polonium, 210.5; final prod-

¹ P. Roy. Soc., A, 81, 280.

² *Ibid.*, 80, 298.

³ Nature, 1908, 119; Phil. Mag., 98, 281 (1909).

⁴ Phil. Mag., June, 1906.

⁵ Nature, Nov. 5, 1908.

uct, lead, 206.5. These values are in good agreement with those determined experimentally. Madame Curie¹ gives the value 226.2 as the atomic weight of radium; Thorpe,² 226.7. The atomic weight of lead is 206.8. Perkin³ obtains about 235 at the atomic weight of the radium emanation. [This value is in good agreement with the calculated value, considering the great experimental difficulties met with in this kind of work. Previous investigators had obtained very discordant results for the atomic weight of radium emanation. In applying Graham's law, that the molecular weights of two gases are inversely proportional to the squares of their coefficients of diffusion, it is necessary to use gases of the same order of molecular weight. For this reason Perkins used mercury vapor. This and the radium emanation resemble each other very much and both are believed to be monatomic.]

On account of the small mass of the electron its expulsion from an atom does not produce any very great rebound of the atom. But when an α -particle is ejected, the rebound causes the atom to move with a very considerable velocity in the opposite direction to that of the α -particle. A study of these atomic motions has recently been made by Russ and Makower.⁴ They find the absorption in air and hydrogen to be an exponential function of the pressure. When an active deposit exists on a solid and is emitting α -rays, it also emits some of its disintegrated atoms.

All experimental evidence indicates that the α -particles from the different radioactive substances are identical in mass and charge and differ only in their initial velocity. They cease to ionize when their velocity falls below $1.5 (10)^9$ cm. per second. No simple relation has been found between ionization and the velocity of the α -particles. Geiger⁵ gives the following numbers for the ions produced by an α -particle from the various radium products:

	Range.	Total number ions produced.
Radium	3.50	1.53 $(10)^5$
Emanation	4.33	1.74 $(10)^5$
Radium A	4.83	1.87 $(10)^5$
Radium C	7.06	2.37 $(10)^5$
Radium F	3.86	1.62 $(10)^5$

¹ Compt. Rend., **145**, 422 (1907).

² P. Roy. Soc., A, **80**, 529.

³ Am. J. Sci., June, 1908.

⁴ Physik. Z., June, 1909.

⁵ P. Roy. Soc., A, **82**, 486 (1909).

III. The β - and γ -Radiations.

It has been known for some time that β -radiations consist of negative corpuscles moving with very great velocities. One of the most important experiments ever made concerning the nature of matter was that of Kaufmann in which he found that the value of e/m depends upon the velocity of the corpuscle. If e is constant this would mean that m increases with the velocity. Assuming that the corpuscle is a sphere of radius a and that it has a charge e at its center, Thomson found that Kaufmann's results agreed with calculated values. In this way all the inertia of the corpuscle could be accounted for by its charge and the estimated value of a (10^{-13} cm.). Recent experiments of Bucherer¹ are also very important in that they give very strong evidence to support the Lorentz-Einstein² theory of relativity.

The fundamental facts of optics and electrodynamics, the aberration of the stars, and many other phenomena indicate that the ether does not take part to any sensible extent³ in the motion of material bodies that are moving through it. The theory of a stagnant ether would lead us to expect a positive result in the celebrated experiments of Michelson and Morley. An explanation of these experiments was given in 1892 by Lorentz. According to his theory, in any material body moving relatively to the ether all of its dimensions in

this direction are decreased by the ratio $\sqrt{1 - \frac{v^2}{V^2}}$ to 1, the directions perpendicular to the motion remaining unchanged. (This contraction is very small and for the earth's diameter in the direction of its orbital motion is 6.5 cm.) V is the velocity of light, and v the velocity of the body with reference to the ether about it. According to the Lorentz theory, an electron at rest is a sphere of radius a , in motion an ellipsoid of revolution with its shorter axis in the direction of motion and equal to $a \sqrt{1 - \frac{v^2}{V^2}}$. Using the Lorentz theory, Bucherer finds that e/m_0 for the β -particle from radium is $1.730 (10)^7$, where m_0 is the mass of the particle at rest.

Considerable work has been done recently on the absorption of β -rays and the secondary radiations which they excite. McClelland⁴ finds that the secondary radiation con-

¹ Physik. Z., Nov. 1, 1908.

² Lorentz: Versuch einer Theorie der elektrischen und optischen Erscheinungen, in bewegten Körpern, Secs. 68, 89, etc. Einstein: Ann. Phys., **17**, 891 (1905).

³ J. J. Thomson: Physik. Z., Aug. 15, 1908.

⁴ P. Roy. Soc., A, **80**, 501.

sists partly of reflected primary rays and partly of corpuscles which appear to have been expelled from the atoms when disturbed by the entry of the primary rays. The relative intensity of the secondary radiation depends directly upon the atomic weight of the element upon which the primary rays fall. Regener¹ finds that β -rays produce scintillations when they strike upon a screen of barium platinocyanide between 10 and 50 cms. from the source. Wilson² shows that the absorption by matter of homogenous β -rays, measured by the ionization, does not take place according to an exponential law, but according to a law which is practically linear.

The rays emitted by uranium X, radium E and actinium are heterogenous. The α -particles lose energy gradually as they pass through matter and finally cease to be effective as ionizing agents. In contrast to this method of absorption Schmidt,³ McClelland and Hackett,⁴ Makower⁵ and others assume that the β -particles are stopped in mid-career while their velocity is still high.

Makower⁵ finds that $5.0 (10)^{10}$ β -particles are emitted per second by the radium C in radioactive equilibrium with one gram of radium.

Investigations on γ -rays are leading more and more to the view⁶ that these rays are practically identical with X-rays, the most notable difference being that γ -rays originate from the same source as the β -rays, whereas X-rays start where cathode rays are stopped.

The nature of X- and γ -rays has been very much discussed recently. According to the theory of Stokes, these rays consist of ether pulses of intense electric and magnetic forces perpendicular to each other and to the direction of motion (as in light). The ionization produced by the rays represents the effect of the electric force in the wave front, causing the ejection of electrons from atoms which it encounters. The ionizing effect of ultraviolet light differs then only in degree from that of γ -rays. Since only a few molecules (one in a billion when the radiation is intense) are ionized, Thomson⁷ believes that ether pulses and waves are localized in limited regions, the wave front possessing a structure similar

¹ Ber. d. physik. Ges., **10**, 351 (1908).

² P. Roy. Soc., A, **82**, 612.

³ Jahrb. der Rad., 1908.

⁴ Trans. Roy. Soc., Dubl., Vol. 9, No. 4 (1907).

⁵ Phil. Mag., January, 1909.

⁶ Eve: Phil. Mag., Aug., 1908.

⁷ P. Phil. Soc., Camb., **14**, 417 (1907).

to bright specks on a dark background. This implies a structure in the ether, which is assumed to have discrete lines disseminated through it. γ -Rays would then simply be pulses along these lines or threads.

Bragg¹ suggests that X- and γ -rays consist of a close association of positive and negative particles which rotate about each other. He believes the negative particle to be the negative electron and suggests that the positive particle may be the "positive" electron (not isolated as yet). The penetrating power would depend upon the distance between the components of the pair. The discontinuous pulse and the neutral pair theories are so much alike that present experimental evidence does not allow us to discriminate between them.

Madsen² finds the γ -rays of radium and possibly of thorium to consist of two distinct homogenous bundles. Secondary γ -radiation appears on both sides of a plate penetrated by a stream of γ -rays. The amount of secondary radiation from the two sides differs very much. Eve³ concludes that a change of hardness of the γ -rays makes but little difference upon the relative intensities of the incident secondary corpuscular radiation, and the intensities follow the order of the atomic weight of the radiators. A change in hardness of the γ -rays makes a marked difference in the relative intensities of the emergent corpuscular secondary radiation from various elements. These secondary radiations do not follow the order of atomic weight.

IV. Temperature Coefficient in Radioactive Changes.

The theory proposed by Rutherford and Soddy to explain the behavior of radioactive changes assumes that the phenomena of radioactivity are accompanied by the disintegration of the atoms of the radio-elements and the production of other elements having distinctive physical and chemical properties. These transformations would therefore be very different from ordinary chemical reactions where the atoms all retain their identity throughout the changes.

An interesting and very important problem which has engaged the attention of several experimenters is whether temperature or pressure change the rate of decay of any radioactive products. This would have an important bearing in geology where radioactive minerals must be considered

¹ Trans. Roy. Soc. South Australia, **31**, 79 (1907); Phil. Mag., Oct., 1907; Nature, Jan. 23, Apr. 16, July 23, July 30, 1908.

² Phil. Mag., **1909**, 423.

³ *Ibid.*, **1909**, 275.

as subject to enormous pressures and high temperatures. Schuster found that the activity of the radium emanation, when subjected for four days to a pressure of 2000 atmospheres, was not changed. Eve showed that a pressure of 20,000 atmospheres did not affect the rate of decay of radium C. Quite a large number of investigators have tried the effect of changing the temperature of the radioactive product.

Engler¹ claims that radioactive changes have a temperature coefficient. Schmidt and Cermak,² however, do not find any temperature coefficient for radium C up to 1500° C. and this was one of the products used by Engler. Forsyth³ concludes that the rate of production of uranium X at 1000° C. is not sensibly different from that at ordinary temperatures. All the results agree in this, that if there is any temperature coefficient at all, it is very small.

One of the enigmas at present is the source of the sun's heat. It has been shown by Newcomb and others that the theory of contraction as expounded by Helmholtz is insufficient to account for the energy the sun loses by radiation. At present, then, no suitable source is known. It has been suggested by Anderson that some elements may be "radioactive" at high temperatures that are not at low temperatures. Our present knowledge of radioactivity, however, does not seem to indicate this. It is very important that experiments along this line should be made.

V. Properties and Distribution of the Radium Emanation.

Radium emanation, on account of its comparatively long period of decay (half-period value, 3.75 days), is being more thoroughly studied than any of the other products of radioactive transformation. Ramsay and Cameron⁴ found 7.07 cubic mm. of emanation in equilibrium with one gram of radium. As this value is much higher than that obtained by calculation, Rutherford⁵ considers that either the assumptions made in the calculations are wrong or Ramsay and Cameron's result is too high.

The emanation is driven from the radium either by heating (830° C.) or by solution. It is then kept over potassium hydroxide for several hours to absorb the carbon dioxide. On cooling the emanation to the temperature of liquid air it will condense and any volatile gases mixed with it can be pumped

¹ Ann. Phys., **1908**, 483.

² Physik. Z., Nov. 15, 1908.

³ Phil. Mag., **1909**, 207.

⁴ J. Chem. Soc., **1907**, 1593.

⁵ Phil. Mag., Aug., 1908.

off. The purity of the emanation was examined spectroscopically.¹ The emanation spectrum in the discharge tube entirely disappeared when the tube was cooled below the liquefying point of the emanation. Ramsay and Cameron² found a very rapid decrease of volume when the emanation was removed from the radium and a more gradual decrease afterwards. Rutherford found a general decrease in volume but did not observe the sudden initial decrease. The emanation obeys Boyle's law.

Rutherford's results, which follow, are in fairly good agreement with the calculated value (0.58 cubic mm.):

		Initial volume of emanation per gram radium.	Final volume of emanation per gram radium.
Experiment	II	1.32	0.59
"	III	0.80	...
"	IV	0.97	0.66
"	V	1.05	0.58

Cameron and Ramsay³ state in their work on the radium emanation that it was extremely difficult to prevent traces of air from leaking into their apparatus during the considerable time which must elapse before an experiment is completed. One-tenth cc. of air contains sufficient argon to be detected spectroscopically and they consider the proof of the formation of argon as being very difficult. On account of the wide distribution of lithium, they also consider it far from easy to prove that lithium did not pre-exist in the solution. But, according to them, the detection of neon is not open to any such objection. Mme. Curie and Mlle. Gleditsch⁴ have repeated the experiments with reference to the transformation of copper into lithium when a copper solution is acted upon by radium emanation and they have obtained no evidence of the production of lithium. Strutt⁵ has shown that the presence of neon can be shown spectroscopically in 0.1 cc. of air, and as Cameron and Ramsay state, it is very hard to avoid a small air leakage in apparatus that is used for a week or more. Rutherford⁶ has repeated their experiments on the action of radium emanation upon a pure water solution.

In preliminary experiments Rutherford found it possible to detect the yellow neon line when $\frac{1}{15}$ cc. of air was intro-

¹ Rutherford and Royds: *Phil. Mag.*, Aug., 1908.

² *Loc. cit.*

³ *J. Chem. Soc.*, 1908, 992.

⁴ *Compt. Rend.*, 147, 345 (1908); *THIS JOURNAL*, 40, 485 (1908).

⁵ *P. Roy. Soc., A*, 80, 572 (1908).

⁶ *Phil. Mag.*, Nov., 1908.

duced into his apparatus, with $\frac{2}{15}$ cc. the red lines of neon flashed out, and with $\frac{2}{10}$ cc. of air a brilliant spectrum of neon was obtained. Experiments similar to those of Cameron and Ramsay were carried out. The residual gas was much smaller in amount than that obtained by Cameron and Ramsay and showed a brilliant spectrum of helium but not a trace of neon. The presence of neon found by Cameron and Ramsay is therefore most likely due to a small leakage of air into their vessel. In the above experiments the use of cocoanut charcoal (cooled with liquid air) to absorb all gases except helium and neon is every essential.

Elster and Geitel found that when a negatively charged wire is exposed in the air a radioactive deposit of radium and thorium is formed upon it. From experiments of this kind it was inferred that the radium emanation was present in the air, coming probably from the ground, which is known to contain a small quantity of radium. The first to make a direct quantitative measurement of the radium emanation in the atmosphere was Eve.¹

A known quantity of air is passed over cocoanut charcoal in glass tubes. The charcoal absorbs the emanation which is afterwards driven off by heating and measured with an electroscope. One cubic meter of air at Montreal was found to contain an amount of emanation equal to that corresponding to $40 (10)^{-12}$ gram of radium when in equilibrium with it. Ashman,² at Chicago, collected the emanation by passing air through vessels cooled with liquid air, the emanation condensing on the sides of the vessels. The amount of emanation in the air varied with the weather conditions, ranging between the values $86 (10)^{-12}$ and $200 (10)^{-12}$. Satterly,³ at Cambridge (England), used the charcoal and liquid air methods and obtained the value $100 (10)^{-12}$ for the amount of emanation. This amount of emanation, together with the disintegration products, would produce about 3 ions per cc. per second. As the number of ions produced in air is ten times this amount, it follows that only a small proportion of the natural ionization of the air is due to the presence of radium emanation and its products. Eve³ gets maximum values for the amount of emanation in the air when there are well-defined cyclones accompanied by heavy rains or a quick thaw of snow. Anticyclones with dry weather and very low temperatures in winter give minimum values. The average amount at Montreal in a year is $60 (10)^{-12}$, the amount vary-

¹ Phil. Mag., Dec., 1907.

² Am. J. Sci., Aug., 1908.

³ Phil. Mag., Oct., 1908.

ing so that the maximum was to the minimum as seven to one. The writer¹ has found the penetrating radiation to be small under anticyclonic conditions.

VI. Radioactivity of the Ordinary Elements.

Ever since the discovery of the radioactivity of uranium investigations have been made to determine if any of the other elements are radioactive. The conclusion of most of the experimenters is that they are not.

A gas in a closed vessel is slightly ionized and this ionization is partly due to the walls of the vessel. By using vessels of the same size and shape and containing the same gas, it is found that the ionization is different for different metals and at first it was considered that this was evidence that ordinary metals are active. But different samples of the same metal cause different amounts of ionization. Lead usually possesses considerable ionizing power. McClennan² has tested quite a large number of different specimens of lead. He measured the ionization in a cylinder of the given metal 60 cm. long and 24 cm. in diameter. The number of ions produced per second per cc. for different specimens of lead varied between 160 and 23. Zinc and aluminium each gave 15. It has been known for some time that there is a very penetrating radiation which, like the γ -rays from radium, makes it necessary to place lead screens several cm. thick about an ionization chamber before it is entirely absorbed. McClennan believes that in the case of aluminium, zinc, and the one sample of lead (23-ion case), the ionizing power was due to this penetrating radiation and secondary radiations excited by it. It is probable that the other samples of lead contain some radioactive impurity. Elster and Geitel³ have been able to extract from some specimens of lead a radioactive substance which resembles radium F.

Greinacher⁴ and Serviss⁵ have examined several metals for a possible temperature gradient. An element might be radioactive and eject α -particles with a velocity less than that required to produce ionization. It would at present be impossible to detect such radiations directly.

In a solid, however, they would soon be stopped and their kinetic energy transformed into heat. The inside of a cylinder made of such a substance would be warmer than the out-

¹ Phys. Rev., June and July, 1908.

² Phil. Mag., Dec., 1907.

³ Physik. Z., Nov., 1906.

⁴ Ann. Phys., 1907, 79.

⁵ Am. J. Sci., Dec., 1907.

side. Very careful measurements have thus far failed to show any such temperature gradient for the ordinary metals.

Campbell and Wood¹ and Wood² have shown that potassium and rubidium salts emit ionizing rays similar to the β -rays of uranium. They estimated the activity of potassium to be about one-thousandth that of uranium. Levin and Ruer³ have investigated various potassium salts photographically and corroborate Wood and Campbell's results. McClennan and Kennedy⁴ have made a more detailed investigation, measuring the saturation current when different salts are spread in uniform layers and placed in an ionization chamber. The activity, as measured by the saturation current, varied directly as the area of the salt exposed. It increased as the thickness of the salt layer was increased until this reached 2.5 mm. when the current became constant. Thirty-five potassium salts were tried. All showed a considerable activity. Lithium, sodium, and ammonium salts showed no activity, caesium and rubidium salts only a very slight amount. Fifteen cm. of air reduced the ionization to half value. The mean value of the absorption constant λ for tin foil was about 125, the value decreasing as the thickness of foil was increased, showing that the rays were not homogenous. Experiments showed that the β -like radiations were not secondary radiations excited by a penetrating radiation such as the γ -rays from radium, for potassium salts do not give rise to any greater proportion of secondary radiation than other salts when exposed to γ -rays. Henriot and Vavon⁵ attempted to concentrate the radioactivity of potassium salts by fractional methods, but with no success. Campbell showed that the β -rays from potassium salts can be deviated by an electric field. Henriot and Vavon deflected the rays with a magnetic field, and the deflection was in such a direction as to indicate that they are negatively charged. Strong⁶ found that various potassium, rubidium and erbium salts are radioactive.

If subatomic changes go on in the atoms of the ordinary elements and α -like particles are ejected, then it would be expected that minerals of these elements would gradually accumulate helium. R. J. Strutt⁷ has examined a large num-

¹ Proc. Phil. Soc., Camb., **14**, I, 15 (1907).

² *Ibid.*, **14** II, (1907).

³ Phys. Z., Apr. 15, 1908.

⁴ Phil. Mag., Sept., 1908.

⁵ Compt. Rend., **149**, 30-32 (1909).

⁶ THIS JOURNAL, **42**, 147 (1909).

⁷ P. Roy. Soc., A, **80**, 572.

ber of minerals and finds that the amount of helium can be accounted for by the radium, uranium and thorium present (beryl being the only exception). The ratio of helium to uranium oxide present should be about 10 if the helium originates from uranium and its products. The following results indicate how closely the ratio approaches 10:

Mineral.	Helium present in cubic mm. per kilogram.	Helium ratio.
Samarskite	1,500,000	14
Haematite	700	9
Galena	2	17
Quartz	2	10

Another argument against the radioactivity of the ordinary elements is the temperature gradient of the earth. The amount of radium in the rocks is more than sufficient to maintain the lower strata of the earth's crust at their present temperature and if the ordinary elements were active, the temperature gradient should be much greater than it is.

Strutt was not able to prove the presence of either argon or neon in the minerals which he examined. According to Cameron and Ramsay's results these gases would be more likely to accumulate in the rocks than helium.

Several potassium minerals gave very large values for the helium ratio, thus indicating that helium may be given off slowly by potassium:

Mineral.	Helium in cubic mm. per 100 grams.	Cc. helium per gram U_3O_8 .
Rock salt	0.223	3.3
Sylvine (KCl)	0.55	256.0
Carnallite ($KMgCl_3 \cdot 6H_2O$)	0.15	47.0
Kieserite ($MgSO_4 \cdot H_2O$)	0.018	0.28

Strutt¹ finds that phosphatic nodules and phosphatized bones of all geological ages possess marked radioactivity, many times higher than that of rocks. This activity is due to products of the uranium series. Helium occurs in these phosphatic materials even when they are not of more than pliocene age. Large values of the helium ratio are not found for the recent deposits but are common for the older ones. Using Rutherford's values, the annual production of helium per gram of the oxide U_3O_8 is $9.13 (10)^{-8}$ cc. By determin-

¹ P. Roy. Soc., A, 81, 272.

ing the helium content we can estimate the age of the mineral. Strutt gives the following:

Phosphatic nodules of the Crag	225,000 years
Phosphatic nodules, Upper Greensand	3,080,000 years
Phosphatic nodules, Lower Greensand	3,950,000 years
Haematite overlying carboniferous limestone	141,000,000 years

W. W. STRONG.

REVIEWS.

DAS ARBEITEN MIT FARBENEMPFINDLICHEN PLATTEN. Von DR. E. KÖNIG. Mit 2 Figuren und 16 instruktiven Tafeln. Berlin: Verlag von Gustav Schmidt. 1909. S. 75. Preis, geh., M. 2.25; geb., M. 2.85.

The majority of books on this subject contain so many formulas for the treatment of photographic plates that the reader is bewildered and at a loss where to begin in his experimental work. This fault cannot be found with the present treatment, which is condensed to 75 pages, and brings the subject down to date. Everything useless has been omitted and the treatment is very clear, especially of the subject of the effects of mixing dyes for the preparation of spectrum plates, and the consequent reduction of absolute sensitiveness for given regions of the spectrum. The book should prove very useful to every photographer who has advanced far enough to use color screens and orthochromatic plates.

R. W. W.

JAHRBUCH DER ELEKTROCHEMIE UND ANGEWANDTEN PHYSIKALISCHEN CHEMIE. Berichte über die Fortschritte des Jahres 1905. Unter Mitwirkung der HERREN DR. P. ASKENASY, Karlsruhe i. B.; DR. P. BERL, Zürich; PROF. DR. K. ELBS, Giessen; DR. F. HARMS, Würzburg; DIREKTOR J. HESS, Lechbruck; PROF. DR. H. LEY, Leipzig; DR. J. MEYER, München; DR. M. ROLOFF, Hagen; DR. O. SACKUR, Breslau. Herausgegeben von DR. PHIL. HEINRICH DANNEEL, Friedrichshagen. XII Jahrgang. Halle a. S.: Verlag von Wilhelm Knapp. 1909. pp. 1049. Price, M. 30.

This well-known "Jahrbuch," which has been of such service in electrochemistry, has acquired enormous proportions. It is divided into scientific electrochemistry and applied electrochemistry, and the scientific portion alone covers 653 pages. The book really covers a much wider field than is usually included under its title, but this is not undesirable.

A criticism that might fairly be offered of the work is that it is so far behind the literature of the subject. We desire referata that are not four years old. It must, however, not

be forgotten that the task of preparing such a work is enormous, and we should be thankful to have such a thorough review of the whole subject even if a little later than we desire. Every scientific library, as well as every electrochemist, should own the work.

H. C. J.

ON THE CALCULATION OF THERMOCHEMICAL CONSTANTS. By H. STANLEY REDGROVE, B.Sc. (Lond.), F.C.S. London: Edward Arnold. 1909. pp. 102.

This little work deals with the thermochemical constants of the hydrocarbons and of organic halogen, oxygen, sulphur and nitrogen compounds. A section is devoted to the thermochemical evidence for Baeyer's strain theory. This work is in convenient form for reference when any of the above-named constants is desired.

H. C. J.

LES DENSITÉS DES SOLUTIONS SUCRÉES À DIFFÉRENTES TEMPÉRATURES. Calculées par D. SIDERSKY, Ingenieur-Chimiste. Paris: H. Dunod et E. Pinat. Brunswick: Friedr. Vieweg et Fils. 1908. pp. 48. Price, Fr. 3.50.

These tables, which are preceded by an introductory statement in French and German, are designed for use in sugar laboratories where it is desired to determine quickly the "apparent purity" of sugar solutions from their specific gravities. They are arranged in two groups: (1) Densities from 0.99567 (water at 30° C.) to 1.01885 (5° Brix at 15° C.) for every degree Centigrade from 10° to 30°, with corresponding sugar contents to hundredths of one per cent. Densities are given as referred to water both at 4° and at 15°. (2) Densities from 1.0188 to 1.1286 (30° Brix at 15° C.) for 10°, 15°, 20°, 25° and 30°, with sugar contents in weight and volume per cents. The tables are clearly printed and conveniently arranged and should prove well adapted to the use for which they are intended.

C. A. R.

HISTOIRE DU DÉVELOPPEMENT DE LA CHIMIE DEPUIS LAVOISIER JUSQU'À NOS JOURS. Par A. LADENBURG, Professeur à l'Université de Breslau. Traduit sur la 4e édition allemande par A. CORVISY, Professeur Agrégé des Sciences Physiques au Lycée Gay-Lussac, Professeur Suppléant à l'École de Médecine et de Pharmacie de Limoges. Paris: Librairie Scientifique A. Hermann et Fils. 1909. pp. xi + 388. Price, Fr. 15.

The fourth edition of Professor Ladenburg's "Entwicklungsgeschichte," of which the present book is a translation, was reviewed in THIS JOURNAL in 1907.¹ Professor Corvisy's translation is very good indeed and the printers have done

¹ Vol. 37, p. 656.

their part well also. It is rather surprising, however, that a book of such permanent value, no matter in what language published, should not be printed on better paper.

C. A. R.

EINFÜHRUNG IN DIE ALLGEMEINE UND ANORGANISCHE CHEMIE AUF ELEMENTARER GRUNDLAGE. Von DR. ALEXANDER SMITH, Professor der Chemie und Direktor des Institutes für allgemeine und physikalische Chemie an der Universität Chicago. Unter Mitwirkung des Verfassers übersetzt und bearbeitet von DR. ERNST STERN, Assistent am Königl. Materialprüfungsamt zu Gross-Lichterfelde-West. Mit einem Vorwort von DR. FRITZ HABER, ord. Professor an der Technischen Hochschule zu Karlsruhe. Karlsruhe i. B.: G. Braunsche Hofbuchdruckerei und Verlag. 1909. pp. xvi + 677.

The following words from Professor Haber's introduction bring out most happily what is perhaps the best feature of Professor Smith's well-known book, *viz.*, the judicious blending of the newer physical-chemical ideas with the older established method of treatment of elementary chemistry: "There are three standpoints from which we can view the broad domains of chemical science and find our way through the multitude of facts which it presents: the comparison of the elements based on the Mendeléeff system; the qualitative representation of the reactions of substances by means of structural formulas; and the quantitative treatment of phenomena on physical-chemical principles. A well-balanced familiarity with the three points of view is an incomparable advantage. The value of a training which will give this balanced knowledge is comparable to that education which gives to young people, to make their way through life, a simultaneous command over several languages. As is well known, during the years when the mind is developing, one language is learned with the other so that both are mastered with equal ease and certainty, while the matured mind which has developed complete facility of expression in one language only familiarizes itself with a foreign language only with difficulty. The use of a single point of view in our science in teaching beginners is as alluring to the academic teacher as to the student. But the more enthusiastically and emphatically this one-sided point of view is taught, the more difficult does the learner afterwards find it to adjust himself to other conceptions when, in the continuation of his studies, they are presented to him, and as the result of such training, we may easily have physical chemists without any sense of constitution or structure, or organic chemists without the physical-chemical insight. This lack of clear understanding easily becomes the source of mutual depreciation and while each group looks upon that side which

it represents as the only important one, all fail to recognize that there is but one chemistry and that the different points of view are all equally fruitful and therefore equally justifiable. Books for beginners in the study of the science which bring out the physical-chemical as well as the structural-chemical side and are based on the Mendeléeff system seem to me, therefore, to furnish the best introduction. In Smith's book, the intent of the author to make the reader familiar with the three general points of view is unmistakable."

In the present translation the English original has been closely followed in the description of experimentally established facts, but in view of the differences in the preparatory training of German and American students the theoretical portions have been considerably revised. The paper and typography are up to the German text-book standard of excellence.

C. A. R.

THE CHEMISTRY AND LITERATURE OF BERYLLIUM. By CHARLES LATHROP PARSONS, B.S., Professor of Inorganic Chemistry in New Hampshire College. Easton, Pa.: The Chemical Publishing Company; London: Williams and Norgate. pp. iv + 180. Price, \$2.00.

Coming from the pen of such an authority on beryllium as Professor Parsons, this book will be found, by every one interested in that element, to be a most valuable, complete and reliable source of information. The history, properties and methods of preparation of the metal and all its known normal, acid and double salts and its basic compounds are given. Says the author: "Especially is it desired to call attention to the fact that a large proportion of its accredited compounds are in reality but indefinite solid solutions. This condition of the literature of beryllium is due to the abnormal extent to which its hydroxide is soluble in solutions of its normal salts, giving rise to solids of almost any degree of basicity or to solutions with decreased osmotic effects. Accordingly, results of analysis, freezing points, etc., give little evidence of the true nature of its compounds, unless accompanied by proved definiteness of composition, a proof too often omitted throughout the whole field of inorganic chemistry, but nowhere more than in studying beryllium and its compounds."

A bibliography is appended, arranged chronologically and extending from 1798 to 1908. Up to 1902, practically all original articles and abstracts are referred to; from 1902 on, only original articles and chief abstracts. Brief abstracts of each article are included.

C. A. R.

LABORATORY NOTES ON INDUSTRIAL WATER ANALYSIS. A Survey Course for Engineers. By ELLEN H. RICHARDS, Instructor in Sanitary Chemistry, Massachusetts Institute of Technology. New York: John Wiley & Sons; London: Chapman & Hall, Limited. 1908. pp. iii + 49. Price, 50 cents.

This little book contains directions for carrying out a few special tests by which the engineer may decide whether any given supply of water is or is not suited for the general purposes for which it is intended to be used, *e. g.*, tests for hardness, excess of carbon dioxide, nitrates, amount of scale-forming material, iron, sulphates, alkalinity, magnesium, action on metals, oxygen consumed, oxygen dissolved, a few "remedies" for defects found, together with tables of hardness, etc., and a brief bibliography.

C. A. R.

INDEX TO VOL. XLII.

AUTHORS.

ACREE S. F. and <i>Slagle, E. A.</i> On the theory of indicators and the reactions of the phthaleins and their salts.....	115 401
<i>Anderson, E.</i> On the action of Fehling's solution on galactose...	401
BENNIGSON, F. See <i>Müller, G.</i>	
<i>Bernthsen, A.</i> and <i>Mohr, E.</i> Kurzes Lehrbuch der organischen Chemie (Review).....	371
<i>Böttger, W.</i> Qualitative Analyse vom Standpunkte der Ionenlehre (Review).....	97
CLARKE, L. See <i>Jackson, C. L.</i>	
<i>Clemmensen, E.</i> and <i>Heitman, A. H. C.</i> Ureides and cyanamides of the oxyfatty acids.	319
<i>Cole, S. W.</i> Exercises in practical physiological chemistry (Review).....	179
<i>Cooper, H. C., Shaw, L. I.</i> and <i>Loomis, N. E.</i> Lead silicates; thermal analysis of the system PbO-SiO ₂	461
<i>Corvisy, A.</i> See <i>Ladenburg, A.</i>	
DAKIN, H. D. The oxidation of hydroxy derivatives of benzaldehyde, acetophenone and related substances..	477
<i>Danneel, H.</i> Jahrbuch der Elektrochemie, 1905 (Review).....	558
<i>Delbridge, T. G.</i> See <i>Orndorff, W. R.</i>	
<i>Dodgson, J. W.</i> See <i>Hanson, E. K.</i>	
FERCHLAND, P. Die englischen elektrochemischen Patente. II. (Review).....	291
<i>Formánek, J.</i> Untersuchung und Nachweis organischer Farbstoffe auf spektroskopischem Wege (Review).....	180
GREINACHER, H. Die neueren Fortschritte auf dem Gebiete der Radioaktivität (Review).....	291
<i>Guest, H. H.</i> See <i>Johnson, T. B.</i>	
HABER, F. See <i>Smith, A.</i>	
<i>Hanson, E. K.</i> and <i>Dodgson, J. W.</i> An intermediate course of laboratory work in chemistry (Review).....	476

- Heitman, A. H. C.* See *Clemmensen, E.*
- Henle, F. W.* and *Thiele, J.* Anleitung für das organisch-präparative Practicum (Review)..... 373
- Henrich, F.* Neuere theoretische Anschauungen auf dem Gebiete der organischen Chemie (Review)..... 372
- Herzog, M.* See *Robertson, W.*
- JACKSON, C. L.* and *Clarke, L.* A modification of Scheibler's extractor for use with large quantities of solid..... 287
- Jänecke, E.* Gesättigte Salzlösungen vom Standpunkte der Phasenlehre (Review)..... 374
- Jones, H. C.* See *Schmidt, M. R.*
- “ See *White, G. F.*
- Jones, L. W.* and *Oesper, R.* The preparation of hydroxamic acids from hydroxylamine salts of organic acids..... 515
- Johnson, T. B.* Researches on pyrimidines: Synthesis of 5-cyanuracil..... 505
- “ and *Guest, H. H.* Researches on amines: synthesis of methylphenylethylamine..... 340
- “ “ “ Researches on pyrimidines: sulphur derivatives of 5-hydroxyuracil: preparation of 5-benzylmercaptouracil and 5-benzylmercaptocytosine..... 271
- “ “ *Mackenzie, K. G.* Researches on pyrimidines: dimethyl derivatives of 2-aminopyrimidine. Preparation of 2-methylamino-5-methylpyrimidine..... 353
- “ See *Wheeler, H. L.*
- KASTLE, J. H.* On the decomposition of the leucosulphonic acids of rosaniline hydrochloride and crystal-violet in aqueous solution..... 293
- Kohler, E. P.* Vinylphenyl ketone and some of its homologues.. 375
- König, E.* Das Arbeiten mit farbenempfindlichen Platten (Review)..... 558
- Kraemer, H.* A text-book of botany and pharmacognosy (Review)..... 98
- LADENBURG, A.* and *Corvisy, A.* Histoire du développement de la chimie (Review)..... 559

<i>Lewis, W. L.</i>	On the action of Fehling's solution on malt sugar..	301
<i>Liddle, L. M.</i>	See <i>Wheeler, H. L.</i>	
<i>Loomis, N. E.</i>	See <i>Cooper, H. C.</i>	
<i>McFARLAND, D. F.</i>	See <i>Wheeler, H. L.</i>	
<i>McKee, R. H.</i>	The oxygen ethers of the dialkylureas.....	1
<i>Mackenzie, K. G.</i>	See <i>Johnson, T. B.</i>	
<i>Meyer, R.</i>	Jahrbuch der Chemie, 1907 (Review).....	370
<i>Mohr, E.</i>	See <i>Bernthsen, A.</i>	
<i>Morgan, J. L. R.</i>	The elements of physical chemistry (Review)..	96
<i>Müller, G. and Bennigson, F.</i>	Die chemische Industrie (Review).	475
<i>NEWELL, L. C.</i>	A course in inorganic chemistry for colleges (Review).....	475
<i>Norden, K.</i>	Elektrolytische Zähler (Review).....	182
<i>OESPER, R.</i>	See <i>Jones, L. W.</i>	
<i>Orndorff, W. R. and Delbridge, T. G.</i>	Tetrachlorgallein and some of its derivatives.....	183
<i>Ostwald, W.</i>	Grundriss der allgemeinen Chemie (Review).....	291
<i>PARSONS, C. L.</i>	The chemistry and literature of beryllium (Re- view).....	561
<i>RAMSAY, W.</i>	Die edlen und die radioaktiven Gase (Review)..	292
"	Production of carbon dioxide from solutions of compounds of silicon, zirconium, bismuth and thorium.....	150
<i>Redgrove, H. S.</i>	On the calculation of thermochemical constants (Review).....	559
<i>Richards, E. H.</i>	Laboratory notes on industrial water analysis (Review).....	562
<i>Robertson, W. and Herzog, M.</i>	Meat and food inspection (Re- view).....	374
<i>SCHMIDT, M. R. and Jones, H. C.</i>	Conductivity and viscosity in mixed solvents containing glycerol.....	37
<i>Segerblom, W.</i>	Tables of properties of over 1500 common inor- ganic substances (Review).....	476
<i>Shaw, L. I.</i>	See <i>Cooper, H. C.</i>	
<i>Sidersky, D.</i>	Les densités des solutions sucrées (Review).....	559
<i>Slagle, E. A.</i>	See <i>Acree, S. F.</i>	
<i>Smith, A.</i>	General chemistry for colleges (Review).....	98
"	<i>Stern, E. and Haber, F.</i> Einführung in die allgemeine und anorganische Chemie (Re- view).....	560

<i>Soddy, F. and Walter, C. H.</i>	Ion (Review).....	181
<i>Stern, E.</i>	See <i>Smith, A.</i>	
<i>Stoddard, J. T.</i>	Quantitative experiments in general chemistry (Review).....	373
<i>Strong, W. W.</i>	Experiments on the radioactivity of erbium, potassium and rubidium compounds.....	147
"	Recent progress in our knowledge of the radio- active elements (Report).....	541
<i>Swartz, C. K.</i>	Relation between crystalline form and chemical constitution (Report).....	158
<i>THIELE, J.</i>	See <i>Henle, F. W.</i>	
<i>VAN'T HOFF, J. H.</i>	Die Lagerung der Atome im Raume (Review)	95
<i>WALTER, C. H.</i>	See <i>Soddy, F.</i>	
<i>Wheeler, H. L. and Johnson, T. B.</i>	Researches on pyrimidines: the preparation of 3-methyl- and 3-benzyluracil.....	30
"	and <i>Liddle, L. M.</i> Researches on halogenamino acids; iodine derivatives of <i>o</i> -toluidine. The 3-iod-amino- benzoic acids.....	498
"	" " Researches on halogenamino acids: iodine derivatives of <i>p</i> -toluidine; 3,5-diiod-4-amino- benzoic acid.....	441
"	" <i>McFarland, D. F.</i> Researches on pyrimi- dines: the action of methyl iodide and of benzyl chlor- ide on 2-oxy-4-methyl-6- methylmercaptopyrimidine.....	431
"	" " Researches on pyrimi- dines: the preparation of 1,4-dimethyluracil and of the monobenzyl deriva- tives of 4-methyluracil...	101
<i>White, G. F. and Jones, H. C.</i>	The effect of temperature and di- lution on the conductivity of or- ganic acids in aqueous solution...	520
<i>Wiley, H. W.</i>	Principles and practice of agricultural analysis. Vol. II (Review).....	99

SUBJECTS.

2-ACETAMINO-5-IODBENZOIC acid.	<i>Wheeler and Liddle</i>	503
Acethydroxamic acid.	<i>Jones and Oesper</i>	519

Acetic acid, conductivity of. <i>White and Jones</i>	528
Acetophenone, benzaldehyde and related substances, oxidation of hydroxy derivatives of. <i>Dakin</i>	477
Amines, researches on: Synthesis of methylphenylethylamine. <i>Johnson and Guest</i>	340
2- and 4-Aminobenzoic acids, conductivity of. <i>White and Jones</i>	533
4-Aminobenzoic acid, action of iodine on. <i>Wheeler and Liddle</i>	457
2-Amino-5-iodobenzoic acid. <i>Wheeler and Liddle</i>	503
2-Amino-5-iodotoluene. <i>Wheeler and Liddle</i>	501
2-Aminopyrimidine, dimethyl derivatives of. <i>Johnson and Mackenzie</i>	353
BENZALDEHYDE, acetophenone and related substances, oxidation of hydroxy derivatives of. <i>Dakin</i>	477
Benzenesulphonemethylphenylethylamine. <i>Johnson and Guest</i> ..	349
Benzenesulphonophenylethylamine. <i>Johnson and Guest</i>	348
Benzenyl-4-amino-3-thiocresol, 448; platinum chloride salt, 448. <i>Wheeler and Liddle</i>	448
Benzoic acid, conductivity of. <i>White and Jones</i>	531
Benzoyldiisobutylurea. <i>McKee</i>	16
β -Benzoylthanesulphonic acid, 390; sodium salt, 389. <i>Kohler</i> ..	390
1-Benzyl-3,4-dimethyluracil. <i>Wheeler and MacFarland</i>	112
1-Benzyl-2-ethylmercapto-4-methyl-6-oxypyrimidine. <i>Wheeler and MacFarland</i>	108
5-Benzylmercaptocytosine. <i>Johnson and Guest</i>	281
2-Benzylmercapto-4-methyl-5-benzyl-6-oxypyrimidine. <i>Wheeler and MacFarland</i>	114
5-Benzylmercaptouracil. <i>Johnson and Guest</i>	279
1- and 3-Benzyl-4-methyluracils. <i>Wheeler and MacFarland</i>	109, 438
Bismuth compounds, carbon dioxide from. <i>Ramsay</i>	157
5-Bromcatechol. <i>Dakin</i>	489
3-Brom-4-hydroxybenzaldehyde, oxidation of. <i>Dakin</i>	491
5-Bromvanillin, oxidation of. <i>Dakin</i>	493
<i>n</i> -Butyric acid, conductivity of. <i>White and Jones</i>	529
CARBON dioxide from compounds of silicon, zirconium, thorium and bismuth. <i>Ramsay</i>	150
Catechol from salicylic aldehyde. <i>Dakin</i>	488
β -Chloropropiophenone. <i>Kohler</i>	389
Cinnamic acid, conductivity of. <i>White and Jones</i>	533
Cobalt chloride, conductivity of solutions in mixed solvents containing glycerol, 69; viscosity and fluidity, 89. <i>Schmidt and Jones</i>	69
Conductivity and viscosity in mixed solvents containing glycerol. <i>Schmidt and Jones</i>	37

Conductivity of organic acids in aqueous solution, effect of temperature and dilution on. <i>White and Jones</i>	520
Crotonyl chloride. <i>Kohler</i>	395
Crystal-violet leucosulphonic acid, decomposition of, in aqueous solution. <i>Kastle</i>	293
Cyanamides and ureides of the hydroxy fatty acids. <i>Clemmensen and Heitman</i>	319
α -Cyan- β -pseudoethylthiourea-acrylpseudoethylthiourea. <i>Johnson</i>	513
5-Cyanuracil, synthesis of. <i>Johnson</i>	505
DIALKYLUREAS, oxygen ethers of. <i>McKee</i>	I
Dibrombutyrophenone. <i>Kohler</i>	393
α,β -Dibrombutyryl-4-bromphenyl ketone. <i>Kohler</i>	397
Dibrombutyryl chloride. <i>Kohler</i>	393
α,β -Dibrommethyl-4-bromphenyl ketone. <i>Kohler</i>	391
3,5-Dibrom-4-hydroxybenzaldehyde, oxidation of. <i>Dakin</i>	491
Dibrom-4-hydroxydiphenylphthalid and its methyl ester. <i>Acree and Slagle</i>	138
Dibromisovalerophenone. <i>Kohler</i>	398
Dibromisovaleryl chloride. <i>Kohler</i>	397
α,β -Dibrompropiophenone. <i>Kohler</i>	382
3,5-Dichlorcatechol. <i>Dakin</i>	489
2,6-Dichlor-5-ethoxypyrimidine. <i>Johnson and Guest</i>	284
3,5-Dichlor-4-hydroxybenzaldehyde, oxidation of. <i>Dakin</i>	490
Diethyl oxalpropionate, stability of sodium salt. <i>Johnson and Mackenzie</i>	367
Diglycolylurea, 326; silver salt, 328. <i>Clemmensen and Heitman</i> ..	326
2,4- and 2,5-Dihydroxyacetophenones, oxidation of. <i>Dakin</i>	495
2,4- and 3,4-Dihydroxybenzaldehydes, oxidation of. <i>Dakin</i>	492
Di- α -hydroxybutyrylurea, 331; silver salt, 332. <i>Clemmensen and Heitman</i>	331
Di- α -hydroxyisovalerylurea, 333; calcium-copper and silver salts, 334. <i>Clemmensen and Heitman</i>	333
1,4-Dihydroxy-3-methoxy-5-brombenzene. <i>Dakin</i>	494
1,4-Dihydroxy-2-nitro-3-methoxybenzene. <i>Dakin</i>	493
3,5-Diiod-4-acetoluide. <i>Wheeler and Liddle</i>	450, 455
3,5-Diiod-4-aminobenzoic acid, 454, 457; ethyl ester, 455; sodium salt, 455. <i>Wheeler and Liddle</i>	454
3,4-Diiodbenzoic acid. <i>Wheeler and Liddle</i>	457
3,5-Diiodbenzoic acid. <i>Wheeler and Liddle</i>	457, 505
3,5-Diiod-4-hydroxybenzaldehyde, oxidation of. <i>Dakin</i>	492
3,5-Diiod-4-hydroxybenzoic acid, 459; methyl ester, 460. <i>Wheeler and Liddle</i>	459
3,5-Diiod-4-methoxybenzoic acid, 461; methyl ester, 461. <i>Wheeler and Liddle</i>	461

2,3-Diiodtoluene. <i>Wheeler and Liddle</i>	452
2,5-Diiodtoluene. <i>Wheeler and Liddle</i>	502
3,5-Diiodtoluene. <i>Wheeler and Liddle</i>	450
3,5-Diiod-4-toluidine. <i>Wheeler and Liddle</i>	449
Diisoamylurea, 17; oxalate, 18. <i>McKee</i>	17
Diisobutylmethylethane. <i>McKee</i>	10
Diisobutylurea, 7; oxalate, 8; picrate, 8. <i>McKee</i>	7
Diisobutylurethane. <i>McKee</i>	12
Dilactylurea, 328; calcium-copper and silver salts, 330. <i>Clemmen-</i> <i>sen and Heitman</i>	328
Dilatometer, new. <i>Acree and Slagle</i>	145
1,4-Dimethyl-3-benzyluracil. <i>Wheeler and McFarland</i>	111
1,4-Dimethyl-2-methylmercapto-6-oxyprymidine. <i>Wheeler and</i> <i>McFarland</i>	105
1,4-Dimethyl-2-oxy-6-methylmercapto-6-oxyprymidine(?) <i>Wheeler and</i> <i>McFarland</i>	440
1,4-Dimethyluracil. <i>Wheeler and McFarland</i>	107
1,3-Diphenyl-5-methylpyrazoline. <i>Kohler</i>	394
Diphenylpyrazoline. <i>Kohler</i>	387
Dipropylmethylethane. <i>McKee</i>	21
Dipropylurethane. <i>McKee</i>	22
2,6-Dithio-5-ethoxyprymidine. <i>Johnson and Guest</i>	285
ERBIUM compounds, radioactivity of. <i>Strong</i>	147
✓ Errata 374,	588
5-Ethoxydithiouracil. <i>Johnson and Guest</i>	285
β-Ethoxyethyl-4-bromphenyl ketone, 392; phenylhydrazone, 392. <i>Kohler</i>	392
Ethoxypropiophenone, 388; phenylhydrazone, 388. <i>Kohler</i>	388
Ethyl α-benzylmercapto-β-hydroxyacrylate. <i>Johnson and Guest</i> .	278
Ethyl benzylthioglycollate. <i>Johnson and Guest</i>	278
Ethyl α-cyan-β-pseudoethylthiourea-acrylate. <i>Johnson</i>	510, 511, 512
Ethyl diisoamylisourea, 18; hydrochloride, 19. <i>McKee</i>	18
Ethyl diisobutylcarbamate. <i>McKee</i>	12
Ethyl dipropylcarbamate. <i>McKee</i>	22
Ethyl dipropylisourea. <i>McKee</i>	22
Ethyl ethoxymethylenecyanacetate, condensation with pseudo- ethylthiourea. <i>Johnson</i>	510, 512
Ethyl-4-hydroxyphenyl ketone, oxidation of. <i>Dakin</i>	496
2-Ethylmercapto-5-benzylmercapto-6-aminopyrimidine. <i>Johnson</i> <i>and Guest</i>	281
2-Ethylmercapto-5-benzylmercapto-6-chlorpyrimidine. <i>Johnson</i> <i>and Guest</i>	280
2-Ethylmercapto-5-benzylmercapto-6-oxyprymidine. <i>Johnson</i> <i>and Guest</i>	279
2-Ethylmercapto-5-carbethoxy-6-aminopyrimidine. <i>Johnson</i>	511, 512

2-Ethylmercapto-4-carboxyl-5-methyl-6-oxypyrimidine, 365; behavior on heating, 368; conversion into thymine, 369; ethyl ester, 368. <i>Johnson and Guest</i>	365
2-Ethylmercapto-5-cyan-6-oxypyrimidine. <i>Johnson</i>	511, 513
2-Ethylmercapto-4-methyl-5-benzyl-6-oxypyrimidine. <i>Wheeler and McFarland</i>	114
2-Ethylmercapto-5-methyl-6-oxypyrimidine. <i>Johnson and MacKenzie</i>	368
2-Ethylmercapto-6-oxypyrimidine, action of methyl iodide on. <i>Wheeler and Johnson</i>	36
Ethyl- α -phenoxy- β -hydroxyacrylate, sodium salt of. <i>Johnson and Guest</i>	285
Extractor, Scheibler's, a modification for use with large quantities of solid. <i>Jackson and Clarke</i>	287
FLUORESCCEIN and its ethyl esters. <i>Acree and Slagle</i>	130
Formhydroxamic acid. <i>Jones and Oesper</i>	518
GALACTOSE, action of Fehling's solution on. <i>Anderson</i>	401
Gallic acid, conductivity of. <i>White and Jones</i>	532
Glycerol, conductivity and viscosity in mixed solvents containing. <i>Schmidt and Jones</i>	37
Glycolylcyanamide. <i>Clemmensen and Heitman</i>	335
Glycolyl thiocyanate. <i>Clemmensen and Heitman</i>	336
HALOGENAMINO acids, researches on:	
Iodine derivatives of 2-toluidine. The 3-iodaminobenzoic acids. <i>Wheeler and Liddle</i>	498
Iodine derivatives of 4-toluidine; 3,5-diiod-4-aminobenzoic acid. <i>Wheeler and Liddle</i>	441
Hydroxamic acids, preparation from hydroxylamine salts of organic acids. <i>Jones and Oesper</i>	515
Hydroxy derivatives of benzaldehyde, acetophenone and related substances, oxidation of. <i>Dakin</i>	477
Hydroxy fatty acids, ureides and cyanamides of. <i>Clemmensen and Heitman</i>	319
2- and 4-Hydroxyacetophenones, oxidation of. <i>Dakin</i>	495
3-Hydroxybenzaldehyde derivatives, oxidation of. <i>Dakin</i>	497
4-Hydroxybenzaldehyde, oxidation of. <i>Dakin</i>	490
2-Hydroxy-5-brombenzaldehyde, oxidation of. <i>Dakin</i>	489
α -Hydroxybutyrylcyanamide. <i>Clemmensen and Heitman</i>	338
2-Hydroxy-5-chlorbenzaldehyde, oxidation of. <i>Dakin</i>	488
2-Hydroxy-3,5-dibrombenzaldehyde, oxidation of. <i>Dakin</i>	489
2-Hydroxy-3,5-dichlorbenzaldehyde, oxidation of. <i>Dakin</i>	488
4-Hydroxydiphenylphthalid. <i>Acree and Slagle</i>	137, 143
α -Hydroxyisovalerylcyanamide. <i>Clemmensen and Heitman</i>	339

Hydroxylamine formate. <i>Jones and Oesper</i>	517
α -Hydroxymethyl- <i>d</i> -ribonic acid, 312; brucine salt, 312; calcium salt, 313; phenylhydrazide, 312. <i>Lewis</i>	312
2-Hydroxy-3-nitrobenzaldehyde, oxidation of. <i>Dakin</i>	490
2-Hydroxy-5-nitrobenzaldehyde, oxidation of. <i>Dakin</i>	490
4-Hydroxyphenylethyl ketone, oxidation of. <i>Dakin</i>	496
5-Hydroxyuracil, sulphur derivatives of. <i>Johnson and Guest</i>	271
INDICATORS, theory of, and the reactions of the phthaleins and their salts. <i>Acree and Slagle</i>	115
2-Iod-3-acetaminobenzoic acid. <i>Wheeler and Liddle</i>	454
3-Iod-4-acetaminobenzoic acid. <i>Wheeler and Liddle</i>	453
3-Iod-4-acetamino-5(?)-nitrobenzene. <i>Wheeler and Liddle</i>	449
2-Iod-3-acettoluide. <i>Wheeler and Liddle</i>	452
3-Iod-4-acettoluide. <i>Wheeler and Liddle</i>	447
3-Iod-4-aminobenzoic acid. <i>Wheeler and Liddle</i>	456
3-Iod-5-aminobenzoic acid. <i>Wheeler and Liddle</i>	504
2-Iod-3-aminotoluene. <i>Wheeler and Liddle</i>	452
3-Iod-4-benztoluide. <i>Wheeler and Liddle</i>	448
3-Iod-5-nitrobenzoic acid. <i>Wheeler and Liddle</i>	503
2-Iod-3-nitrotoluene. <i>Wheeler and Liddle</i>	451
3-Iod-4-toluidine, 445; hydrochloride, 446; oxalate, 447. <i>Wheeler and Liddle</i>	445
3-Iod-4-tolylurea. <i>Wheeler and Liddle</i>	447
Isobutenylphenyl ketone, 398; phenylhydrazone, 399. <i>Kohler</i>	398
Isovanillin, oxidation of. <i>Dakin</i>	497
LACTYLCYANAMIDE. <i>Clemmensen and Heitman</i>	337
Lactyl thiocyanate. <i>Clemmensen and Heitman</i>	338
Lead silicates: thermal analysis of the system PbO-SiO_2 . <i>Cooper, Shaw and Loomis</i>	461
Lithium bromide, conductivity of solutions in mixed solvents containing glycerol, 66; viscosity and fluidity, 89. <i>Schmidt and Jones</i>	66
MALONIC acid, conductivity of. <i>White and Jones</i>	530
Malt sugar, action of Fehling's solution on. <i>Lewis</i>	301
1-Methyl-2-acetamino-5-iodbenzene. <i>Wheeler and Liddle</i>	502
2-Methylamino-4-carboxyl-5-methyl-6-oxypyrimidine, 369; hydrochloride, 370; methylamine salt, 370. <i>Johnson and Mackenzie</i>	369
2-Methylamino-4-methyl-6-chlorpyrimidine, 363; reduction product with zinc, 364. <i>Johnson and Mackenzie</i>	363
2-Methylamino-5-methyl-6-chlorpyrimidine. <i>Johnson and Mackenzie</i>	361
2-Methylamino-4-methyl-6-oxypyrimidine. <i>Johnson and Mackenzie</i>	363

2-Methylamino-5-methyl-6-oxypyrimidine, 359; platinum chloride salt, 361; picrate, 360; sulphate, 360. <i>Johnson and Mackenzie</i>	359
2-Methylamino-5-methylpyrimidine, 362; hydrochloride, 363; picrate, 363. <i>Johnson and Mackenzie</i>	362
1-Methyl-2-benzamino-5-iodobenzene. <i>Wheeler and Liddle</i>	502
Methyl benzoyldiisobutylisourea, 15; action of hydrochloric acid on, 15; hydrochloride, 16. <i>McKee</i>	16
4-Methyl-5-benzyluracil. <i>Wheeler and McFarland</i>	114
Methyl diisoamylisourea, 17; action of hydrochloric acid on, 18; hydrochloride, 17. <i>McKee</i>	17
Methyl diisobutylcarbamate. <i>McKee</i>	10
Methyl diisobutylisourea, 3; action of benzoyl chloride on, 14; of hydrochloric acid, 8; of water, 12; ferrocyanide, 7; hydrochloride, 6. <i>McKee</i>	3
Methyl dimethylisourea, 22; action of water on, 25; stability of, 27; hydrochloride, 26. <i>McKee</i>	22
Methyl dipropylcarbamate. <i>McKee</i>	21
Methyl dipropylisourea, 20; action of hydrochloric acid on, 21; hydrochloride, 20. <i>McKee</i>	20
2-Methylmercapto-5-ethoxy-6-chlorpyrimidine. <i>Johnson and Guest</i>	282
2-Methylmercapto-5-ethoxy-6-thiopyrimidine. <i>Johnson and Guest</i>	283
2-Methylmercapto-4-methyl-6-chlorpyrimidine. <i>Wheeler and McFarland</i>	435
2-Methylmercapto-4-methyl-6-thiopyrimidine. <i>Wheeler and McFarland</i>	435
Methylphenylethylamine, 349; acid oxalate, 351; hydrochloride, 350; platinum chloride salt, 351; picrate, 351; picrolonate, 351. <i>Johnson and Guest</i>	349
1,1-Methylphenylethyl-2- α -naphthylurea. <i>Johnson and Guest</i> ..	352
1,1-Methylphenylethyl-2-phenylthiourea. <i>Johnson and Guest</i> ...	352
1,1-Methylphenylethyl-2-phenylurea. <i>Johnson and Guest</i>	352
1,1-Methylphenylethylurea. <i>Johnson and Guest</i>	352
4-Methyl-6-thiouracil. <i>Wheeler and McFarland</i>	437
3-Methyluracil. <i>Wheeler and Johnson</i>	35
4-Methyluracil, monobenzyl derivatives of, 101; action of benzyl chloride on, 110. <i>Wheeler and McFarland</i>	101
3 - NITRO - 4 - HYDROXYBENZALDEHYDE, oxidation of. <i>Dakin</i>	491
2- and 5-Nitrovanillins, oxidation of. <i>Dakin</i>	492
OBITUARY:	
Samuel William Johnson.....	474

Organic acids in aqueous solution, effect of temperature and dilution on conductivity of. <i>White and Jones</i>	520
2-Oxy-3-benzyl-6-methylmercaptopyrimidine. <i>Wheeler and Johnson</i>	35
2-Oxy-3,4-dimethyl-6-methylmercaptopyrimidine. <i>Wheeler and McFarland</i>	439
2-Oxy-6-methylmercaptopyrimidine. <i>Wheeler and Johnson</i>	34
2 - Oxy - 4 - methyl - 6 - metadinitrophenylmercaptopyrimidine. <i>Wheeler and McFarland</i>	440
2 - Oxy - 3 - methyl - 6 - methylmercaptopyrimidine. <i>Wheeler and Johnson</i>	34
2-Oxy-4-methyl-6-methylmercaptopyrimidine, action of methyl iodide and benzyl chloride on. <i>Wheeler and McFarland</i> ...	431
2 - Oxy - 4 - methyl - 6 - orthonitrobenzylmercaptopyrimidine. <i>Wheeler and McFarland</i>	440
PHENOLPHTHALEIN, dilatometer measurements with solutions of. <i>Acree and Slagle</i>	
Phenolphthalin. <i>Acree and Slagle</i>	135
5-Phenoxyuracil. <i>Johnson and Guest</i>	286
Phenylacetic acid, conductivity of. <i>White and Jones</i>	529
1-Phenyl-3-bromphenyl-5-methylpyrazoline. <i>Kohler</i>	397
Phenylethylamine, 346; hydriodide, 347. <i>Johnson and Guest</i> ...	346
1-Phenylethyl-2- α -naphthylurea. <i>Johnson and Guest</i>	348
β -Phenylisovalerophenone, 400; oximes, 400; phenylhydrazone, 400. <i>Kohler</i>	400
Phthaleins and their salts, reactions of, and the theory of indicators. <i>Acree and Slagle</i>	115
2-Phthalic acid, conductivity of. <i>White and Jones</i>	531
Potassium compounds, radioactivity of. <i>Strong</i>	147
Potassium iodide, conductivity of solutions in mixed solvents containing glycerol, 73; viscosity and fluidity, 89. <i>Schmidt and Jones</i>	73
Propenylbromphenyl ketone. <i>Kohler</i>	396
Propenylphenyl ketone. <i>Kohler</i>	393
Propionic acid, conductivity of. <i>White and Jones</i>	528
Pyrimidines, researches on:	
Action of methyl iodide and of benzyl chloride on 2-oxy-4-methyl-6-methylmercaptopyrimidine. <i>Wheeler and McFarland</i>	431
Dimethyl derivatives of 2-methylaminopyrimidine. The preparation of 2-methylamino-5-methylpyrimidine. <i>Johnson and Mackenzie</i>	353
Preparation of 1,4-dimethyluracil and of the monobenzyl derivatives of 4-methyluracil. <i>Wheeler and McFarland</i> ...	101

Preparation of 3-methyl- and 3-benzyluracil. <i>Wheeler and Johnson</i>	30
Sulphur derivatives of 5-hydroxyuracil: preparation of 5-benzylmercaptouracil and 5-benzylmercaptocytosine. <i>Johnson and Guest</i>	271
Synthesis of 5-cyanuracil. <i>Johnson</i>	505
 RADIOACTIVITY of potassium, erbium and rubidium compounds. <i>Strong</i>	147
Reports:	
Recent progress in our knowledge of the radioactive elements. <i>Strong</i>	541
Relation between crystalline form and chemical constitution. <i>Swartz</i>	158
Resacetophenone, and its methyl and ethyl ethers, oxidation of. <i>Dakin</i>	495
Reviews:	
Agricultural analysis, principles and practice of. <i>Wiley</i>	99
Allgemeine und anorganische Chemie, Einführung in die. <i>Smith, Stern and Haber</i>	560
Allgemeine Chemie, Grundriss der. <i>Ostwald</i>	291
Beryllium, the chemistry and literature of. <i>Parsons</i>	561
Botany and pharmacognosy, a text-book of. <i>Kraemer</i>	98
Chemie, Jahrbuch der, 1907. <i>Meyer</i>	370
Chemische Industrie, die. <i>Müller and Bennigson</i>	475
Edlen und die radioaktiven Gase, die. <i>Ramsay</i>	292
Elektrochemie, Jahrbuch der, 1905. <i>Danneel</i>	558
Elektrolytische Zähler. <i>Norden</i>	182
Englischen elektrochemischen Patente, die. II. <i>Ferchland</i> .	291
Farbenempfindlichen Platten, das Arbeiten mit. <i>König</i>	558
General chemistry for colleges. <i>Smith</i>	98
Gesättigte Salzlösungen vom Standpunkte der Phasenlehre. <i>Jänecke</i>	374
Histoire du développement de la chimie. <i>Ladenburg and Corvisy</i>	559
Inorganic chemistry for colleges, a course of. <i>Newell</i>	475
Ion. <i>Soddy and Walter</i>	181
Laboratory work in chemistry, an intermediate course of. <i>Hanson and Dodgson</i>	476
Lagerung der Atome im Raume, die. <i>Van't Hoff</i>	95
Meat and food inspection. <i>Robertson and Herzog</i>	374
Neuere theoretische Anschauungen auf dem Gebiete der organischen Chemie. <i>Henrich</i>	372
Organischen Chemie, kurzes Lehrbuch der. <i>Bernthsen and Mohr</i>	371

Organischer Farbstoffe, Untersuchung und Nachweis, auf spektroskopischem Wege. <i>Formánek</i>	180
Organisch-präparative Practicum, Anleitung für das. <i>Henle and Thiele</i>	373
Physical chemistry, the elements of. <i>Morgan</i>	96
Physiological chemistry, exercises in practical. <i>Cole</i>	179
Properties of over 1500 common inorganic substances, tables of. <i>Segerblom</i>	476
Qualitative Analyse vom Standpunkte der Ionenlehre. <i>Böttger</i>	97
Quantitative experiments in general chemistry. <i>Stoddard</i> ..	373
Radioaktivität, die neueren Fortschritte auf dem Gebiete der. <i>Greinacher</i>	291
Sucrées, densités des solutions. <i>Sidersky</i>	559
Thermochemical constants, on the calculation of. <i>Redgrove</i>	559
Water analysis, laboratory notes on industrial. <i>Richards</i> ...	562
Rosaniline hydrochloride leucosulphonic acid, decomposition of, in aqueous solution. <i>Kastle</i>	293
Rubidium compounds, radioactivity of. <i>Strong</i>	147
SALICYLIC acid, conductivity of. <i>White and Jones</i>	532
Salicylic aldehyde, oxidation of. <i>Dakin</i>	486, 497
Scheibler's extractor, a modification for use with large quantities of solid. <i>Jackson and Clarke</i>	287
Silicon compounds, carbon dioxide from. <i>Ramsay</i>	157
Succinic acid, conductivity of. <i>White and Jones</i>	530
Sulphanilic acid, conductivity of. <i>White and Jones</i>	534
TETRABROMPHENOLPHTHALEIN and its ethyl ester. <i>Acree and Slagle</i>	136
Tetrachlorgallein, 207; barium salt, 224; hydrate, 220; hydrochloride, 212; lead salt, 221; potassium salt, 217; sodium salt, 213. <i>Orndorff and Delbridge</i>	207
Tetrachlorgallein dimethyl ether diacetate. <i>Orndorff and Delbridge</i>	252
Tetrachlorgallein ethyl ester. <i>Orndorff and Delbridge</i>	243
Tetrachlorgallein methyl ester, 236; hydrochloride, 242. <i>Orndorff and Delbridge</i>	236
Tetrachlorgallein tetracetate. <i>Orndorff and Delbridge</i>	226
Tetrachlorgallein tetramethyl ether. <i>Orndorff and Delbridge</i> ...	249
Tetrachlorgallein tetraphenylcarbamate. <i>Orndorff and Delbridge</i> .	235
Tetrachlorgallein trimethyl ether, 244; acetate, 248; ammonium and sodium salts, 246; hydrochloride, 247. <i>Orndorff and Delbridge</i>	244
Tetrachlorgallin tetracetate, 229; silver salt, 232. <i>Orndorff and Delbridge</i>	229

2-Thio-5-benzylmercapto-6-oxypyrimidine. <i>Johnson and Guest.</i>	282
2-Thio-4-methyl-5-benzyluracil. <i>Wheeler and McFarland.</i>	113
2-Thio-5-phenoxy-6-oxypyrimidine. <i>Johnson and Guest.</i>	286
6-Thiouracil. <i>Wheeler and Johnson.</i>	33
Thorium compounds, carbon dioxide from. <i>Ramsay.</i>	153
Thymine. <i>Johnson and Mackenzie.</i>	369
4-Toluenesulphonophenylethylamine. <i>Johnson and Guest.</i>	349
2-Toluidine, iodine derivatives of. <i>Wheeler and Liddle.</i>	498
4-Toluidine, iodine derivatives of. <i>Wheeler and Liddle.</i>	441
3,4,5-Triiodobenzoic acid, 458; sodium salt, 459. <i>Wheeler and Liddle.</i>	458
3,4,5-Triiodotoluene. <i>Wheeler and Liddle.</i>	450
Trimethylphenylethylammonium iodide. <i>Johnson and Guest.</i>	348
URACIL-5-CARBOXAMIDE. <i>Johnson.</i>	514
Ureides and cyanamides of the hydroxy fatty acids. <i>Clemmensen and Heitman.</i>	319
VANILLIN, oxidation of. <i>Dakin.</i>	492
Vinylphenyl ketone and some of its homologues. <i>Kohler.</i>	375
Viscosity and conductivity in mixed solvents containing glycerol. <i>Schmidt and Jones.</i>	37
ZIRCONIUM compounds, carbon dioxide from. <i>Ramsay.</i>	156

FORMULAS.

C₁-GROUP.**1 III.**

CH ₃ O ₂ N. Formhydroxamic acid. <i>Jones and Oesper.</i>	518
CH ₅ O ₃ N. Hydroxylamine formate. <i>Jones and Oesper.</i>	517

C₂-GROUP.**2 II.**

C ₂ H ₄ O ₂ . Acetic acid. <i>White and Jones.</i>	528
---	-----

2 III.

C ₂ H ₅ O ₂ N. Acethydroxamic acid. <i>Jones and Oesper.</i>	519
---	-----

C₃-GROUP.**3 II.**

C ₃ H ₄ O ₄ . Malonic acid. <i>White and Jones.</i>	530
C ₃ H ₆ O ₂ . Propionic acid. <i>White and Jones.</i>	528
C ₃ H ₈ O ₃ . Glycerol. <i>Schmidt and Jones.</i>	37

3 III.

C ₃ H ₄ O ₂ N ₂ . Glycolylcyanamide. <i>Clemmensen and Heitman.</i>	335
---	-----

3 IV.

$C_3H_3O_2NS$. Glycolyl thiocyanate. *Clemmensen and Heitman*. 336

C₄-GROUP.

4 II.

$C_4H_6O_4$. Succinic acid. *White and Jones*. 530

$C_4H_8O_2$. *n*-Butyric acid. *White and Jones*. 529

4 III.

C_4H_5OCl . Crotonyl chloride. *Kohler*. 395

$C_4H_6O_2N_2$. Lactylcyanamide. *Clemmensen and Heitman*. 337

$C_4H_{10}ON_2$. Methyl dimethylimidocarbamate. *McKee*. 22, 25, 27

4 IV.

$C_4H_4ON_2S$. 2-Oxy-6-thiopyrimidine (6-thiouracil). *Wheeler and Johnson*. 33

$C_4H_5OClBr_2$. α,β -Dibromobutyryl chloride. *Kohler*. 393

$C_4H_6O_2NS$. Lactyl thiocyanate. *Clemmensen and Heitman*. 338

$C_4H_{11}ON_2Cl$. Methyl dimethylimidocarbamate hydrochloride. *McKee*. 26

C₅-GROUP.

5 III.

$C_5H_8O_2N_3$. 2,6-Dioxy-5-cyanpyrimidine. *Johnson*. 514

$C_5H_5O_3N_3$. 2,6-Dioxy-5-carboxamidepyrimidine. *Johnson*. 514

$C_5H_6O_2N_2$. (1) 2,6-Dioxy-3-methylpyrimidine. *Wheeler and Johnson*. 35

(2) 2,6-Dioxy-4-methylpyrimidine. *Wheeler and McFarland*. 110

(3) 2,6-Dioxy-5-methylpyrimidine (thymine). *Johnson and Mackenzie*. 369

$C_5H_8O_2N_2$. α -Hydroxybutyrylcyanamide. *Clemmensen and Heitman*. 338

$C_5H_8O_5N_2$. Diglycolylurea. $Ag_2 + 2.5 H_2O$ (p. 328). *Clemmensen and Heitman*. 326

5 IV.

$C_5H_6ON_2S$. (1) 2-Oxy-6-methylmercaptopyrimidine. *Wheeler and Johnson*. 34

(2) 2-Oxy-4-methyl-6-thiopyrimidine. *Wheeler and McFarland*. 437

$C_5H_7OClBr_2$. α,β -Dibromisovaleryl chloride. *Kohler*. 397

C₆-GROUP.

6 II.

$C_6H_6O_2$. 1,2-Dihydroxybenzene (catechol). *Dakin*. 488

$C_6H_9N_3$. (1) 2-Methylamino-4-methylpyrimidine. $2 + ZnCl_2$. *Johnson and Mackenzie*. 364

(2) 2-Methylamino-5-methylpyrimidine. *Johnson and Mackenzie*. 362

$C_6H_{12}O_6$.	Galactose. <i>Anderson</i>	401
$C_6H_{12}O_7$.	α -Hydroxymethyl- <i>d</i> -ribonic acid. <i>Lewis</i>	312

6 III.

$C_6H_4O_2Cl_2$.	(1) 1,2-Dihydroxy-3,5-dichlorbenzene. <i>Dakin</i>	489
	(2) 1,4-Dihydroxy-3,5-dichlorbenzene. <i>Dakin</i>	491
$C_6H_5O_2Br$.	1,2-Dihydroxy-5-brombenzene. <i>Dakin</i>	489
$C_6H_8O_2N_2$.	1,4-Dimethyl-2,6-dioxypyrimidine. <i>Wheeler and McFarland</i>	107
$C_6H_8N_2S_2$.	2 - Methylmercapto - 4 - methyl - 6 - thiopyrimidine. <i>Wheeler and McFarland</i>	435
$C_6H_5N_3Cl$.	(1) 2-Methylamino-4-methyl-6-chlorpyrimidine. <i>Johnson and Mackenzie</i>	363
	(2) 2-Methylamino-5 - methyl - 6 - chlorpyrimidine. <i>Johnson and Mackenzie</i>	361
$C_6H_9ON_3$.	(1) 2-Methylamino-4-methyl-6-oxypyrimidine. <i>Johnson and Mackenzie</i>	363
	(2) 2 - Methylamino - 5 - methyl - 6 - oxypyrimidine. + H_2O . <i>Johnson and Mackenzie</i>	359
$C_6H_{10}O_2N_2$.	α -Hydroxyisovalerylcyanamide. <i>Clemmensen and Heitman</i>	339
$C_6H_{10}N_3Cl$.	2-Methylamino - 5 - methylpyrimidine hydrochloride. + H_2O . <i>Johnson and Mackenzie</i>	363

6 IV.

$C_6H_6ON_2Cl_2$.	2,6 - Dichlor - 5 - ethoxypyrimidine. <i>Johnson and Guest</i>	284
$C_6H_7O_3NS$.	4-Aminobenzenesulphonic acid (sulphanilic acid). <i>White and Jones</i>	534
$C_6H_7N_2ClS$.	2 - Methylmercapto - 4 - methyl - 6 - chlorpyrimidine. <i>Wheeler and McFarland</i>	435
$C_6H_8ON_2S$.	(1) 2 - Ethylmercapto - 6 - oxypyrimidine. <i>Wheeler and Johnson</i>	36
	(2) 2-Oxy-3-methyl-6-methylmercaptopyrimidine. <i>Wheeler and Johnson</i>	34
	(3) 2-Oxy-4-methyl-6-methylmercaptopyrimidine. <i>Wheeler and McFarland</i>	437
$C_6H_8ON_2S_2$.	2,6-Dithio-5-ethoxypyrimidine. <i>Johnson and Guest</i> .	285
$C_6H_{10}ON_3Cl$.	2-Methylamino-5-methyl-6-oxypyrimidine hydrochloride. 2 + $PtCl_4$. <i>Johnson and Mackenzie</i>	361
$C_6H_{11}O_6N_3S$.	2-Methylamino-5-methyl-6-oxypyrimidine sulphate. <i>Johnson and Mackenzie</i>	360

C₇-GROUP.

7 II.

$C_7H_5I_3$.	1-Methyl-3,4,5-triiodbenzene. <i>Wheeler and Liddle</i>	450
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$C_7H_6O_2$. (1) Benzoic acid. <i>White and Jones</i>	531
(2) 2-Hydroxybenzaldehyde (salicylic aldehyde). <i>Dakin</i> ...	486, 497
(3) 4-Hydroxybenzaldehyde. <i>Dakin</i>	490
$C_7H_6O_3$. (1) 2,4-Dihydroxybenzaldehyde. <i>Dakin</i>	492
(2) 3,4-Dihydroxybenzaldehyde. <i>Dakin</i>	492
(3) 2-Hydroxybenzoic acid (salicylic acid). <i>White and Jones</i>	532
$C_7H_6O_5$. 3,4,5-Trihydroxybenzoic acid (gallic acid). <i>White and Jones</i>	532
$C_7H_6I_2$. (1) 1-Methyl-2,3-diiodbenzene. <i>Wheeler and Liddle</i> ...	452
(2) 1-Methyl-2,5-diiodbenzene. <i>Wheeler and Liddle</i>	502
(3) 1-Methyl-3,5-diiodbenzene. <i>Wheeler and Liddle</i>	450

7 III.

$C_7H_3O_2I_3$. 3,4,5-Triiodbenzoic acid. Na + 2.5 H_2O (p. 459). <i>Wheeler and Liddle</i>	458
$C_7H_4O_2Cl_2$. (1) 3,5-Dichlor-4-hydroxybenzaldehyde. <i>Dakin</i> ...	490
(2) 2-Hydroxy-3,5-dichlorbenzaldehyde. <i>Dakin</i>	488
$C_7H_4O_2Br_2$. (1) 2-Hydroxy-3,5-dibrombenzaldehyde. <i>Dakin</i> ...	489
(2) 3,5-Dibrom-4-hydroxybenzaldehyde. <i>Dakin</i>	491
$C_7H_4O_2I_2$. (1) 3,4-Diiodbenzoic acid. <i>Wheeler and Liddle</i>	457
(2) 3,5-Diiodbenzoic acid. <i>Wheeler and Liddle</i>	458, 505
(3) 3,5-Diiod-4-hydroxybenzaldehyde. <i>Dakin</i>	492
$C_7H_4O_3I_2$. 3,5-Diiod-4-hydroxybenzoic acid. <i>Wheeler and Liddle</i> .	459
$C_7H_5O_2Cl$. 2-Hydroxy-5-chlorbenzaldehyde. <i>Dakin</i>	488
$C_7H_5O_2Br$. (1) 3-Brom-4-hydroxybenzaldehyde. <i>Dakin</i>	491
(2) 2-Hydroxy-5-brombenzaldehyde. <i>Dakin</i>	489
$C_7H_5O_4N$. (1) 2-Hydroxy-3-nitrobenzaldehyde. <i>Dakin</i>	490
(2) 2-Hydroxy-5-nitrobenzaldehyde. <i>Dakin</i>	490
(3) 3-Nitro-4-hydroxybenzaldehyde. <i>Dakin</i>	491
$C_7H_7O_2N$. (1) 2-Aminobenzoic acid. <i>White and Jones</i>	533
(2) 4-Aminobenzoic acid. <i>Wheeler and Liddle</i>	457
<i>White and Jones</i>	534
$C_7H_7O_3Br$. 1,4-Dihydroxy-3-methoxy-5-brombenzene. <i>Dakin</i> ...	494
$C_7H_7O_5N$. 1,4-Dihydroxy-2-nitro-3-methoxybenzene. <i>Dakin</i> ...	493
$C_7H_7NI_2$. 1-Methyl-3,5-diiod-4-aminobenzene. <i>Wheeler and Liddle</i>	449
C_7H_8NI . (1) 1-Methyl-2-amino-5-iodbenzene. <i>Wheeler and Liddle</i>	501
(2) 1-Methyl-2-iod-3-aminobenzene. <i>Wheeler and Liddle</i>	452
(3) 1-Methyl-3-iod-4-aminobenzene. <i>Wheeler and Liddle</i>	445
$C_7H_9O_3N_3$. 2 - Methylamino - 4 - carboxyl - 5 - methyl - 6 - oxy-pyrimidine. <i>Johnson and Mackenzie</i>	369
$C_7H_{12}O_5N_2$. Dilactylurea. $Ag_2 + 1.5 H_2O$ (p. 330). <i>CaCu</i> (p. 330). <i>Clemmensen and Heitman</i>	328

7 IV.

$C_7H_4O_4NI$	3-Iod-5-nitrobenzoic acid. <i>Wheeler and Liddle</i>	503
$C_7H_5O_2N_2I$	3,5-Diiod-4-aminobenzoic acid. $Na + 5H_2O$ (p. 455). <i>Wheeler and Liddle</i>	454, 457
$C_7H_6O_2NI$	(1) 2-Amino-5-iodbenzoic acid. <i>Wheeler and Liddle</i>	503
	(2) 3-Iod-4-aminobenzoic acid. <i>Wheeler and Liddle</i>	456
	(3) 3-Iod-5-aminobenzoic acid. <i>Wheeler and Liddle</i>	504
	(4) 1-Methyl-2-iod-3-nitrobenzene. <i>Wheeler and Liddle</i>	451
$C_7H_7ON_3S$	2-Ethylmercapto-5-cyan-6-oxypyrimidine. <i>Johnson</i> 511, 513	
C_7H_9NCII	1 - Methyl - 3 - iod - 4 - aminobenzene hydrochloride. <i>Wheeler and Liddle</i>	446
$C_7H_{10}ON_2S$	(1) 1,4 - Dimethyl - 2 - methylmercapto - 6 - oxy- pyrimidine. <i>Wheeler and McFarland</i>	105
	(2) 1,4 - Dimethyl - 2 - oxy - 6 - methylmercaptopyrimidine(?) <i>Wheeler and McFarland</i>	440
	(3) 2 - Ethylmercapto - 5 - methyl - 6 - oxypyrimidine. <i>John-</i> <i>son and Mackenzie</i>	369
	(4) 2 - Oxy - 3,4 - dimethyl - 6 - methylmercaptopyrimidine. <i>Wheeler and McFarland</i>	439
$C_7H_{10}ON_2S_2$	2 - Methylmercapto - 5 - ethoxy - 6 - thiopyrimidine. <i>Johnson and Guest</i>	283
$C_7H_{10}O_3N_3Cl$	2 - Methylamino - 4 - carboxyl - 5 - methyl - 6 - oxypyrimidine hydrochloride. <i>Johnson and Mackenzie</i>	370

7 V.

$C_7H_9ON_2ClS$	2 - Methylmercapto - 5 - ethoxy - 6 - chlorpyrimi- dine. <i>Johnson and Guest</i>	282
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C₈-GROUP.

8 II.

$C_8H_6O_4$	2-Phthalic acid. <i>White and Jones</i>	531
$C_8H_8O_2$	(1) Methyl-2-hydroxyphenyl ketone. <i>Dakin</i>	495
	(2) Methyl-4-hydroxyphenyl ketone. <i>Dakin</i>	495
	(3) Phenylacetic acid. <i>White and Jones</i>	529
$C_8H_8O_3$	(1) 3-Hydroxy-4-methoxybenzaldehyde (isovanillin). <i>Dakin</i>	497
	(2) 3-Methoxy-4-hydroxybenzaldehyde (vanillin). <i>Dakin</i> ..	492
	(3) Methyl-2,4-dihydroxyphenyl ketone (resacetophenone). <i>Dakin</i>	495
	(4) Methyl-2,5-dihydroxyphenyl ketone. <i>Dakin</i>	496
$C_8H_{11}N$	Phenylethylamine. <i>Johnson and Guest</i>	346

8 III

$C_8H_6O_3I_2$	(1) 3,5-Diiod-4-methoxybenzoic acid. <i>Wheeler and</i> <i>Liddle</i>	461
	(2) Methyl 3,5-diiod-4-hydroxybenzoate. <i>Wheeler and Liddle</i>	460

$C_8H_7O_3Br$. 3-Methoxy-4-hydroxy-5-brombenzaldehyde (brom-vanillin). <i>Dakin</i>	493
$C_8H_7O_5N$. (1) 3 - Methoxy - 4 - hydroxy - 5 - nitrobenzaldehyde. <i>Dakin</i>	492
(2) 2-Nitro-3-methoxy-4-hydroxybenzaldehyde. <i>Dakin</i>	493

8 IV.

$C_8H_{11}O_3N$. Ethyl ethoxymethylenecyanacetate. <i>Johnson</i>	510, 512
$C_8H_{12}NI$. Phenylethylamine hydriodide. <i>Johnson and Guest</i>	347
$C_8H_{14}O_3N_4$. 2 - Methylamino - 4 - carboxyl - 5 - methyl - 6 - oxy-pyrimidine methylamine salt. <i>Johnson and Mackenzie</i>	370
$C_8H_{17}O_2N$. Methyl dipropylcarbamate. <i>McKee</i>	21
$C_8H_{18}ON_2$. Methyl dipropylimidocarbamate. <i>McKee</i>	20, 21
$C_8H_9ON_2I$. 1-Methyl-3-iod-4-aminophenylurea. <i>Wheeler and Liddle</i>	447
$C_8H_{10}O_3N_2S$. 2 - Ethylmercapto - 4 - carboxyl - 5 - methyl - 6 - oxypyrimidine. <i>Johnson and Mackenzie</i>	365, 368, 369
$C_8H_{19}ON_2Cl$. Methyl dipropylimidocarbamate hydrochloride. <i>McKee</i>	20

C₉-GROUP.

9 II.

C_9H_8O . Vinylphenyl ketone. <i>Kohler</i>	386
$C_9H_8O_2$. β -Phenylacrylic acid (cinnamic acid). <i>White and Jones</i>	533
$C_9H_{10}O_2$. Ethyl-4-hydroxyphenyl ketone. <i>Dakin</i>	496
$C_9H_{10}O_3$. Methyl-2-hydroxy-4-methoxyphenyl ketone. <i>Dakin</i> ..	496
$C_9H_{13}N$. Methylphenylethylamine. <i>Johnson and Guest</i>	349
$C_9H_{14}O_5$. Diethyl oxalpropionate. <i>Na. Johnson and Mackenzie</i> .	367

9 III.

$C_9H_7OBr_3$. α,β -Dibromomethyl-4-bromphenyl ketone. <i>Kohler</i>	391
$C_9H_8OBr_2$. α,β -Dibromopropylphenyl ketone. <i>Kohler</i>	382
$C_9H_8O_3I_2$. Methyl 3,5-diiod-4-methoxybenzoate. <i>Wheeler and Liddle</i>	461
C_9H_9OCl . β -Chloropropylphenyl ketone. <i>Kohler</i>	389
$C_9H_{10}O_4S$. β -Benzoylthanesulphonic acid. <i>Na + H₂O</i> (p. 389). <i>Kohler</i>	390
$C_9H_{14}NCl$. Methylphenylethylamine hydrochloride. + 2H ₂ O. 2 + PtCl ₄ (p. 351). <i>Johnson and Guest</i>	350
$C_9H_{16}O_5N_2$. Di- α -hydroxybutyrylurea. <i>Ag₂ + 1.5H₂O</i> (p. 332). <i>Clemmensen and Heitman</i>	331
$C_9H_{19}O_2N$. Ethyl dipropylcarbamate. <i>McKee</i>	22
$C_9H_{20}ON_2$. (1) Diisobutylurea. <i>McKee</i>	7
(2) Ethyl dipropylimidocarbamate. <i>McKee</i>	22

9 IV.

$C_9H_8O_3NI$.	(1) 2-Acetamino-5-iodbenzoic acid. <i>Wheeler and Liddle</i>	503
	(2) 2-Iod-3-acetaminobenzoic acid. <i>Wheeler and Liddle</i>	454
	(3) 3-Iod-4-acetaminobenzoic acid. <i>Wheeler and Liddle</i>	453
$C_9H_9ONI_2$.	1-Methyl-3,5-diiod-4-acetaminobenzene. <i>Wheeler and Liddle</i>	450, 455
$C_9H_9O_2NI_2$.	Ethyl 3,5-diiod-4-aminobenzoate. <i>Wheeler and Liddle</i>	455
$C_9H_{10}ONI$.	(1) 1-Methyl-2-acetamino-5-iodbenzene. <i>Wheeler and Liddle</i>	502
	(2) 1-Methyl-2-iod-3-acetaminobenzene. <i>Wheeler and Liddle</i>	452
	(3) 1-Methyl-3-iod-4-acetaminobenzene. <i>Wheeler and Liddle</i>	447
$C_9H_{10}ON_3Cl$.	2 - Methylamino - 5 - methyl - 6 - oxypyrimidine hydrochloride. 2 + $PtCl_4$. <i>Johnson and Guest</i>	361
$C_9H_{10}O_3N_2I$.	1 - Methyl - 3 - iod - 4 - acetamino-5(?) - nitrobenzene. <i>Wheeler and Liddle</i>	449
$C_9H_{11}O_5N_3S$.	2 - Methylamino - 5 - methyl - 6 - oxypyrimidine sulphate. <i>Johnson and Mackenzie</i>	360
$C_9H_{13}O_2N_3S$.	(1) Ethyl α - cyan - β - pseudoethylthiourea - acrylate. <i>Johnson</i>	510, 511, 512
	(2) 2 - Ethylmercapto - 5 - carbethoxy - 6 - aminopyrimidine. <i>Johnson</i>	511, 512

C₁₀-GROUP.

10 II.

$C_{10}H_{10}O$.	Propenylphenyl ketone. <i>Kohler</i>	393
$C_{10}H_{12}O_3$.	Methyl-2-hydroxy-4-ethoxyphenyl ketone. <i>Dakin</i>	496

10 III.

$C_{10}H_8O_3N_2$.	2,6-Dioxy-5-phenoxy-pyrimidine. <i>Johnson and Guest</i> ..	286
$C_{10}H_9OBr$.	Propenylbromphenyl ketone. <i>Kohler</i>	396
$C_{10}H_9OBr_3$.	α,β -Dibrombutyryl-4-bromphenyl ketone. <i>Kohler</i>	397
$C_{10}H_{10}OBr_2$.	α,β -Dibrombutyrylphenyl ketone. <i>Kohler</i>	393
$C_{10}H_{14}ON_2$.	1,1-Methylphenylethylurea. <i>Johnson and Guest</i>	352
$C_{10}H_{21}O_2N$.	Methyl diisobutylcarbamate. <i>McKee</i>	10
$C_{10}H_{22}ON_2$.	Methyl diisobutylimidocarbamate. <i>McKee</i>	3, 8, 12, 14

10 IV.

$C_{10}H_8O_2N_2S$.	2-Thio-5-phenoxy-6-oxypyrimidine. <i>Johnson and Guest</i>	286
$C_{10}H_{14}O_3N_2S$.	2 - Ethylmercapto - 4 - carboxyl - 5 - methyl - 6 - oxypyrimidine ethyl ester. <i>Johnson and Mackenzie</i>	368
$C_{10}H_{15}ON_5S_2$.	α - Cyan - β - pseudoethylthiourea-acrylpseudoethylthiourea. <i>Johnson</i>	513
$C_{10}H_{23}ON_2Cl$.	Methyl diisobutylisourea hydrochloride. <i>McKee</i> ..	6

C₁₁-GROUP.**11 II.**

C ₁₁ H ₁₂ O.	Isobutenylphenyl ketone. <i>Kohler</i>	398
C ₁₁ H ₁₂ O ₄ .	Ethyl α -phenoxy- β -hydroxyacrylate. <i>Na. Johnson and Guest</i>	285
C ₁₁ H ₁₄ O ₂ .	Ethoxypropylphenyl ketone. <i>Kohler</i>	388

11 III.

C ₁₁ H ₁₂ OBr ₂ .	α,β -Dibromisovalerylphenyl ketone. <i>Kohler</i>	398
C ₁₁ H ₁₃ O ₂ Br.	β -Ethoxyethyl-4-bromphenyl ketone. <i>Kohler</i>	392
C ₁₁ H ₁₄ O ₂ S.	Ethyl benzylthioglycollate. <i>Johnson and Guest</i>	278
C ₁₁ H ₁₅ O ₄ N.	Methylphenylethylamine acid oxalate. <i>Johnson and Guest</i>	351
C ₁₁ H ₁₈ NI.	Trimethylphenylethylammonium iodide. <i>Johnson and Guest</i>	348
C ₁₁ H ₂₀ O ₆ N ₂ .	Di- α -hydroxyisovalerylurea. Ag ₂ + 2.5H ₂ O (p. 334). CaCu (p. 334). <i>Clemmensen and Heitman</i>	333
C ₁₁ H ₂₃ O ₂ N.	Ethyl diisobutylcarbamate. <i>McKee</i>	12
C ₁₁ H ₂₄ ON ₂ .	Diisoamylurea. <i>McKee</i>	17

11 IV.

C ₁₁ H ₈ O ₅ N ₄ S.	2 - Oxy - 4 - methyl - 6 - metadinitrophenylmercaptopyrimidine. <i>Wheeler and McFarland</i>	440
C ₁₁ H ₁₀ ON ₂ S ₂ .	2-Thio-5-benzylmercapto-6-oxypyrimidine. <i>Johnson and Guest</i>	282
C ₁₁ H ₁₀ O ₂ N ₂ S.	2,6-Dioxy-5-benzylmercaptopyrimidine. <i>Johnson and Guest</i>	279
C ₁₁ H ₁₁ ON ₃ S.	2-Oxy-5-benzylmercapto-6-aminopyrimidine. <i>Johnson and Guest</i>	281

C₁₂-GROUP.**12 II.**

C ₁₂ H ₂₂ O ₁₁ .	Malt sugar. + H ₂ O. <i>Lewis</i>	301
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12 III.

C ₁₂ H ₁₂ O ₂ N ₂ .	(1) 1 - Benzyl - 2,6 - dioxy - 4 - methylpyrimidine. <i>Wheeler and McFarland</i>	109, 438
	(2) 2,6 - Dioxy - 3 - benzyl - 4 - methylpyrimidine. <i>Wheeler and McFarland</i>	110, 439
	(3) 2,6 - Dioxy - 4 - methyl - 5 - benzylpyrimidine. <i>Wheeler and McFarland</i>	114
C ₁₂ H ₁₄ O ₃ S.	Ethyl α -benzylmercapto- β -hydroxyacrylate. <i>Johnson and Guest</i>	278
C ₁₂ H ₂₆ ON ₂ .	Methyl diisoamylimidocarbamate. <i>McKee</i>	17, 18

12 IV.

$C_{12}H_{11}O_3N_3S$. 2 - Oxy - 4 - methyl - 6 - orthonitrobenzylmercaptopyrimidine. <i>Wheeler and McFarland</i>	440
$C_{12}H_{12}ON_2S$. (1) 2 - Oxy - 3 - benzyl - 6 - methylmercaptopyrimidine. <i>Wheeler and Johnson</i>	35
(2) 2-Thio-4-methyl-5-benzyl-6-oxypyrimidine. <i>Wheeler and McFarland</i>	113
$C_{12}H_{27}ON_2Cl$. Methyl diisoamylimidocarbamate hydrochloride. <i>McKee</i>	17

C₁₃-GROUP.

13 III.

$C_{13}H_{14}O_2N_2$. (1) 1 - Benzyl - 2,6 - dioxy - 3,4 - dimethylpyrimidine. <i>Wheeler and McFarland</i>	112
(2) 1,4-Dimethyl-2,6-dioxy-3-benzylpyrimidine. <i>Wheeler and McFarland</i>	111
$C_{13}H_{15}N_3S_2$. 2 - Ethylmercapto - 5 - benzylmercapto - 6 - aminopyrimidine. <i>Johnson and Guest</i>	281
$C_{13}H_{28}ON_2$. Ethyl diisoamylimidocarbamate. <i>McKee</i>	18

13 IV.

$C_{13}H_{13}N_2ClS_2$. 2 - Ethylmercapto - 5 - benzylmercapto - 6 - chlorpyrimidine. <i>Johnson and Guest</i>	280
$C_{13}H_{14}ON_2S_2$. 2 - Ethylmercapto - 5 - benzylmercapto - 6 - oxypyrimidine. <i>Johnson and Guest</i>	279
$C_{13}H_{29}ON_2Cl$. Ethyl diisoamylimidocarbamate hydrochloride. <i>McKee</i>	19

C₁₄-GROUP.

14 III.

$C_{14}H_{11}NS$. Benzenyl-2-amino-5-methylthiophenol. <i>Wheeler and Liddle</i>	448
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14 IV.

$C_{14}H_{12}ONI$. (1) 1-Methyl-2-benzamino-5-iodobenzene. <i>Wheeler and Liddle</i>	502
(2) 1-Methyl-3-iod-4-benzaminobenzene. <i>Wheeler and Liddle</i>	448
$C_{14}H_{12}NCIS$. Benzenyl - 2 - amino - 5 - methylthiophenol hydrochloride. 2 + $PtCl_4$ + H_2O . <i>Wheeler and Liddle</i>	448
$C_{14}H_{15}O_2NS$. Benzenesulphonephenylethylamine. <i>Johnson and Guest</i>	348
$C_{14}H_{16}ON_2S$. (1) 1 - Benzyl-2-ethylmercapto - 6 - oxypyrimidine. <i>Wheeler and McFarland</i>	108
(2) 2 - Ethylmercapto - 4 - methyl-5-benzyl-6-oxy-pyrimidine. <i>Wheeler and McFarland</i>	114

C₁₅-GROUP.**15 II.**

$C_{15}H_{14}N_2$.	Diphenylpyrazoline.	<i>Kohler</i>	387
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15 III.

$C_{15}H_{16}O_7N_4$.	Methylphenylethylamine picrate.	<i>Johnson and Guest</i>	351
$C_{15}H_{23}O_8N_5$.	Diisobutylurea picrate.	<i>McKee</i>	8

15 IV.

$C_{15}H_{17}O_2NS$.	(1) Benzenesulphonemethylphenylethylamine.	<i>Johnson and Guest</i>	349
	(2) 4-Methylbenzenesulphonephenylethylamine.	<i>Johnson and Guest</i>	349

C₁₆-GROUP.**16 II.**

$C_{16}H_{16}N_2$.	1,3-Diphenyl-5-methylpyrazoline.	<i>Kohler</i>	394
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16 III.

$C_{16}H_{16}N_2Br$.	1 - Phenyl - 3 - bromphenyl - 5 - methylpyrazoline.	<i>Kohler</i>	397
$C_{16}H_{18}ON_2$.	1,1-Methylphenylethyl-2-phenylurea.	<i>Johnson and Guest</i>	352
$C_{16}H_{18}N_2S$.	1,1-Methylphenylethyl-2-phenylthiourea.	<i>Johnson and Guest</i>	352
$C_{16}H_{24}O_2N_2$.	Benzoyldiisobutylurea.	<i>McKee</i>	16

16 IV.

$C_{16}H_{18}O_4N_2I_2$.	1-Methyl-3-iod-4-aminobenzene oxalate.	<i>Wheeler and Liddle</i>	447
$C_{16}H_{20}ON_8Fe$.	Methyl diisobutylisourea ferrocyanide.	<i>McKee</i> .	7

C₁₇-GROUP.**17 II.**

$C_{17}H_{18}O$.	β -Phenylisovalerylphenyl ketone.	<i>Kohler</i>	400
$C_{17}H_{18}N_2$.	Isobutenylphenyl ketone phenylhydrazone.	<i>Kohler</i> ..	399

17 III.

$C_{17}H_{19}ON$.	β -Phenylisovalerylphenyl ketone oximes.	<i>Kohler</i> ...	400
$C_{17}H_{20}ON_2$.	Ethoxypropylphenyl ketone phenylhydrazone.	<i>Kohler</i>	388
$C_{17}H_{26}O_2N_2$.	Methyl benzoyldiisobutylisourea.	<i>McKee</i>	15

17 IV.

$C_{17}H_{19}ON_2Br$. β -Ethoxyethyl-4-bromophenyl ketone phenylhydrazone. <i>Kohler</i>	392
$C_{17}H_{27}O_2N_2Cl$. Methyl benzoyldiisobutylisourea hydrochloride. <i>McKee</i>	16

C₁₈-GROUP.

18 III.

$C_{18}H_{21}O_7N_9$. 2-Methylamino-5-methylpyrimidine picrate. <i>Johnson and Mackenzie</i>	363
$C_{18}H_{21}O_9N_9$. 2 - Methylamino - 5 - methyl - 6 - oxypyrimidine picrate. + H_2O . <i>Johnson and Guest</i>	360

C₁₉-GROUP.

19 III.

$C_{19}H_{18}ON_2$. 1-Phenylethyl-2- α -naphthylurea. <i>Johnson and Guest</i>	348
$C_{19}H_{21}O_5N_5$. Methylphenylethylamine picronolate. <i>Johnson and Guest</i>	351

19 IV.

$C_{19}H_{18}ON_2S$. 2 - Benzylmercapto - 4 - methyl - 5 - benzyl - 6 - oxy - pyrimidine. <i>Wheeler and McFarland</i>	114
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C₂₀-GROUP.

20 II.

$C_{20}H_{12}O_5$. Fluorescein. <i>Acree and Slagle</i>	130
$C_{20}H_{14}O_3$. 4-Hydroxydiphenylphthalid. <i>Acree and Slagle</i>	137, 143
$C_{20}H_{14}O_4$. Phenolphthalein. <i>Acree and Slagle</i>	141
$C_{20}H_{16}O_4$. Phenolphthalin. <i>Acree and Slagle</i>	135

20 III.

$C_{20}H_8O_7Cl_4$. Tetrachlorgallein. + H_2O (p. 220). Ba + 3 H_2O (p. 224). K + 4 H_2O (p. 217). Na + 4 H_2O (p. 213). <i>Orndorff and Delbridge</i>	207
$C_{20}H_9O_7Cl_5$. Tetrachlorgallein hydrochloride. <i>Orndorff and Delbridge</i>	212
$C_{20}H_{12}O_3Br_2$. Dibrom - 4 - hydroxydiphenylphthalid. <i>Acree and Slagle</i>	138
$C_{20}H_{12}O_4Br_4$. Tetrabromphenolphthalin. <i>Acree and Slagle</i>	136
$C_{20}H_{20}ON_2$. 1,1 - Methylphenylethyl - 2 - α - naphthylurea. <i>Johnson and Guest</i>	352
$C_{20}H_{42}O_6N_4$. Diisobutylurea oxalate. <i>McKee</i>	8

20 V.

$C_{20}H_{22}O_3N_3ClS$. Rosaniline hydrochloride leucosulphonic acid. <i>Kastle</i>	293
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C₂₁-GROUP.**21 III.**

C ₂₁ H ₁₀ O ₇ Cl ₄ . Tetrachlorgallein methyl ester. <i>Orndorff and Delbridge</i>	236
C ₂₁ H ₁₁ O ₇ Cl ₅ . Tetrachlorgallein methyl ester hydrochloride. <i>Orndorff and Delbridge</i>	242
C ₂₁ H ₁₄ O ₃ Br ₂ . Methyl ester of dibrom-4-hydroxydiphenylphthalid. <i>Acree and Slagle</i>	139

C₂₂-GROUP.**22 II.**

C ₂₂ H ₁₆ O ₅ . Ethyl esters of fluorescein. Na (p. 132). <i>Acree and Slagle</i>	131
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22 III.

C ₂₂ H ₁₂ O ₇ Cl ₄ . Tetrachlorgallein ethyl ester. <i>Orndorff and Delbridge</i>	243
C ₂₂ H ₁₆ O ₄ Br ₄ . Ethyl ester of tetrabromphenolphthalin. <i>Acree and Slagle</i>	137

C₂₃-GROUP.**23 II.**

C ₂₃ H ₂₄ N ₂ . β -Phenylisovalerylphenyl ketone phenylhydrazone. <i>Kohler</i>	400
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23 III.

C ₂₃ H ₁₄ O ₇ Cl ₄ . Tetrachlorgallein trimethyl ether. Na (p. 246). NH ₄ (p. 247). <i>Orndorff and Delbridge</i>	244
C ₂₃ H ₁₆ O ₇ Cl ₅ . Tetrachlorgallein trimethyl ether hydrochloride. <i>Orndorff and Delbridge</i>	247

C₂₄-GROUP.**24 II.**

C ₂₄ H ₂₀ O ₅ . Diethyl esters of fluorescein. <i>Acree and Slagle</i>	131
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24 III.

C ₂₄ H ₁₆ O ₇ Cl ₄ . Tetrachlorgallein tetramethyl ether. <i>Orndorff and Delbridge</i>	249
C ₂₄ H ₅₀ O ₆ N ₄ . Diisoamylurea oxalate. <i>McKee</i>	18

24 IV.

C ₂₄ H ₁₀ O ₁₁ Cl ₄ Pb ₃ . Salt obtained from lead acetate and sodium salt of tetrachlorgallein. <i>Orndorff and Delbridge</i>	221
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C₂₅-GROUP.**25 III.**

- $C_{25}H_{10}O_8Cl_4$. Tetrachlorgallein trimethyl ether acetate. *Orndorff* and *Delbridge*..... 248

25 V.

- $C_{25}H_{32}O_3N_3ClS$. Crystal-violet leucosulphonic acid. *Kastle*..... 293

C₂₆-GROUP.**26 III.**

- $C_{26}H_{10}O_9Cl_4$. Tetrachlorgallein dimethyl ether diacetate. *Orndorff* and *Delbridge*..... 252

C₂₈-GROUP.**28 III.**

- $C_{28}H_{16}O_{11}Cl_4$. Tetrachlorgallein tetracetate. *Orndorff* and *Delbridge*..... 226
- $C_{28}H_{18}O_{11}Cl_4$. Tetrachlorgallin tetracetate. + 1.5 C_2H_6O . Ag (p. 232). *Orndorff* and *Delbridge*..... 229

C₄₈-GROUP.**48 IV.**

- $C_{48}H_{28}O_{11}N_4Cl_4$. Tetrachlorgallein tetraphenylcarbamate. *Orndorff* and *Delbridge*..... 235

ERRATA.

- ✓ Vol. 42, p. 282, l. 14, for $C_{11}H_{10}ON_2S$ read $C_{11}H_{10}ON_2S_2$.
- ✓ Vol. 42, p. 393, l. 12 from bottom, for $C_{10}H_{11}OBr_2$ read $C_{10}H_{10}OBr_2$.
- ✓ Vol. 42, p. 400, l. 5 and 23, for β -phenylisobutyrophenone read β -phenylisovalerophenone.
- ✓ Vol. 42, p. 447, l. 11, for $C_{16}H_{18}O_2N_2I_2$ read $C_{16}H_{18}O_4N_2I_2$.
- ✓ Vol. 42, p. 449, l. 18, for $C_9H_9O_3N_2I$ read $C_9H_{10}O_3N_2I$.

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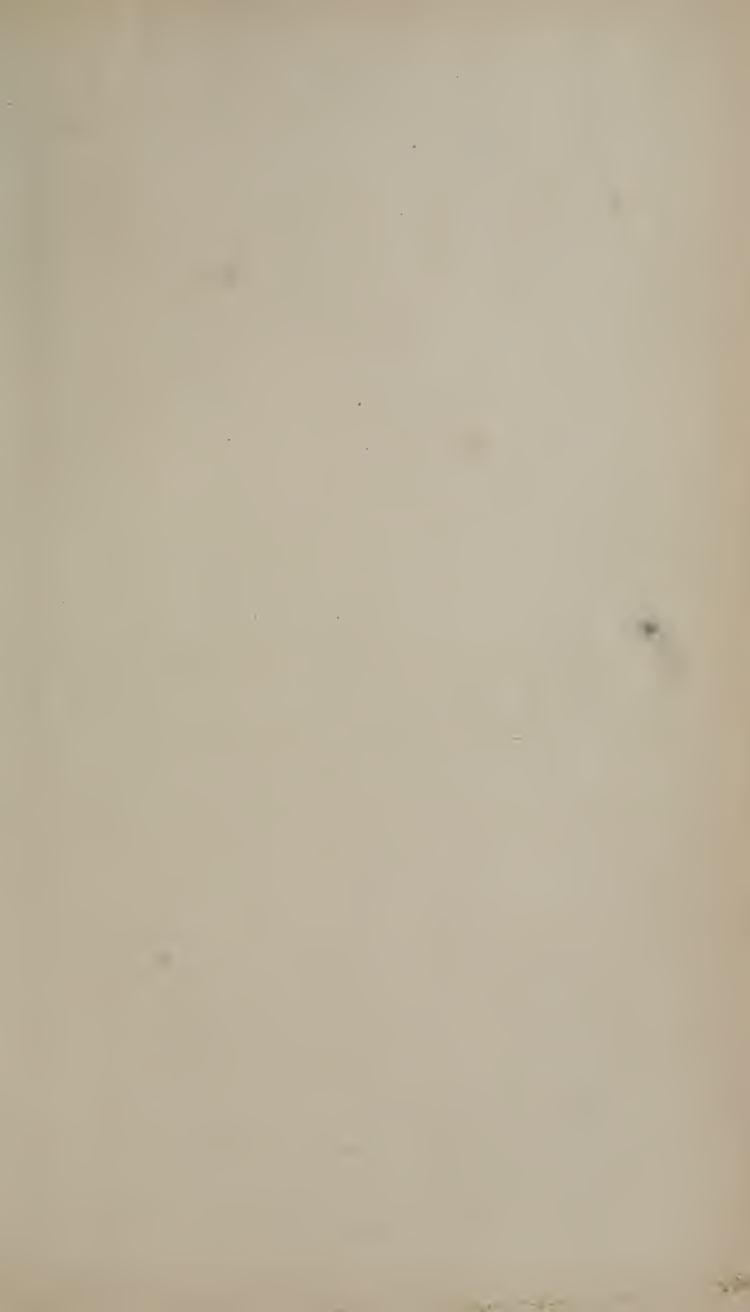
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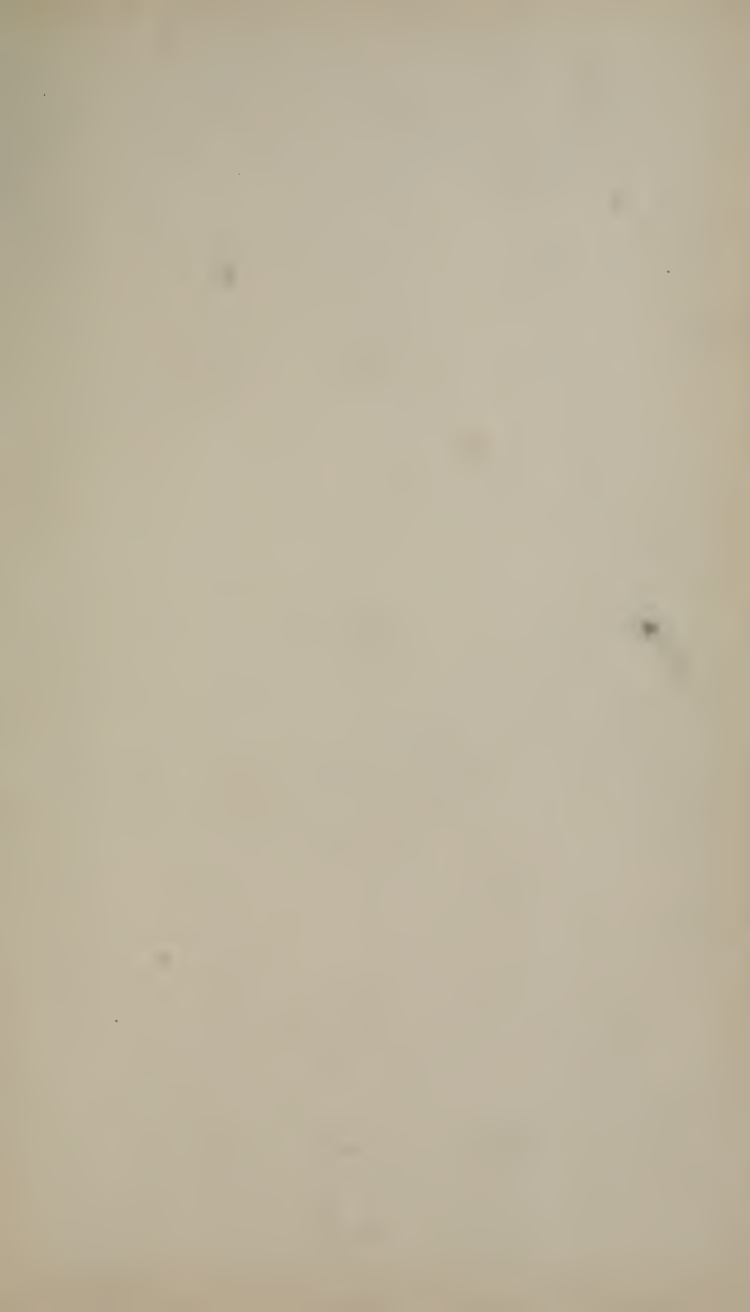
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